King County Department of Natural Resources and Parks

Combined Sewer Overflow Treatment Systems Evaluation and Testing

Phase 2

Subtask 340 – Pilot Test Report

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List of Abbreviations

Al	Aluminum
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand (5-day)
C2	Recycled Water
C3	Chlorinated Secondary Effluent
CDM	Camp Dresser & McKee
CEPT	Chemically Enhanced Primary Treatment
CFD	Computational Fluid Dynamics
CFU	Coliform Units
COD	Chemical Oxygen Demand
CSO	Combined Sewer Overflow
DI	Deionized Water
DOE	Department of Ecology (State of Washington)
$FeCl_3$	Ferric Chloride
ft	feet
ft^2	square feet
ft/min	feet per minute
gpd/ft^2	gallons per day per square foot
gpm	gallons per minute
gpm/sf	gallons per minute per square feet
hp	horse power
HRC	Highrate Clarification
KC	King County
MGD	Million Gallons per Day

min	minute
mL	milliliter
mL/L/hr	milliliter per liter per hour
NaOCl	Sodium hypochlorite
NaOH	Sodium Hydroxide
NTU	nephelometric turbidity units
NPDES	National Pollution Discharge Elimination System
O&M	Operations and maintenance
PAX	Polyaluminum Chloride
Poly	Polymer
pH	hydrogen ion activity
PI	Primary Influent
rpm	revolutions per minute
RWSP	King County's Regional Wastewater Services Plan
sf	square feet
SOR	Surface Overflow Rate
TSS	Total Suspended Solids
UV	Ultraviolet light or radiation
UV-245	Ultraviolet radiation at a wavelength of 245 nanometers
UVT	Ultraviolet transmittance
VSS	Volatile Suspended Solids

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Section 1
Executive Summary

King County's Regional Wastewater Services Plan (RWSP) calls for development of satellite Combined Sewer Overflow (CSO) treatment facilities. The 5-year CSO program update from 2005 recommended that King County continue to monitor high rate treatment for potential consideration for CSOs at the King/Kingdome, Hanford/Lander, Brandon and Michigan sites. Likewise, the 2006 CSO Control Program Review recommended that pilot tests "be conducted on promising new CSO treatment technologies." The purpose of this project was to develop and implement a pilot test program to evaluate and compare potential CSO treatment technologies, assess whether or not the technologies are ready to meet County performance goals in full-scale CSO treatment facilities, and make recommendations based on that assessment. This report presents the findings of the pilot testing and summarizes the pilot program.

1.1 Project Objectives

The pilot project was developed in two phases. Phase 1 examined the range of treatment technologies used on CSOs and identified a technology that could benefit from pilot testing. Pilot testing occurred in Phase 2 and was conducted to provide the information necessary for potential full-scale application of the technology for King County CSOs. The Phase 1 technology review focused on the following goals:

- Helping King County reach a firm process selection for control of the Duwamish CSO's
- Making sure the technology chosen can be upgraded to meet future, more stringent requirements
- Identifying a technology that could benefit from pilot testing

The pilot technology was selected based on its ability to support these goals and answer the following:

- Does the pilot work help the County meet discharge criteria for constituents of concern?
- Does the pilot work being considered shed light on the effectiveness of alternative disinfectants and provide design criteria?
- Does the technology pilot yield new information that may support changing from baseline CSO treatment approach of primary treatment and chlorine disinfection?
- Does the selected technology result in a treatment strategy that is less costly than the current recommended alternative?

In Phase 1, CEPT technology combined with plates (CEPT+plates) was identified as the CSO technology to pilot test. Previously, the 2006 CSO Plan Update indicated that up to 70% removal of total suspended solids (TSS) was possible with CEPT without plates when surface overflow rates (SOR) were less than approximately 14,400 gpd/ ft^2, with a typical operating range of 1,400 gpd/ ft^2 to 7,200 gpd/ ft^2. Additionally, the plan stated that CEPT+plates could be operated as high as 43,200 gpd/ ft^2, albeit with diminished performance. To evaluate these rates and determine the potential application of the CEPT+plates technology for King County CSOs, a pilot of the CEPT and CEPT+plates technologies was conducted.

Phase 2 of the project implemented the pilot work including development of a work and test plan, a one year field program and completion of the final report. The objective of the Phase 2 pilot testing program was to assess how plate settlers influenced the effectiveness of the CEPT technology when the two were operated in conjunction with one another, to provide design criteria for the technology, and to determine specific performance capabilities based on King County's CSO treatment needs. To meet this objective and to provide a structured approach that would yield sufficient data and information, the work and test plan developed in Phase 2 identified eight primary and eight secondary objectives or inquiries for the pilot project to address. Ten different testing scenarios were developed to answer these objectives and were run between February and November, 2009 on simulated CSO events on the pilot unit. In total, approximately 60 trial runs were completed.

Simulated CSO events were used for the pilot testing because there were very few actual peak wet weather events at West Point during this period and a simulated event provided a more predictable, reliable and controllable testing environment. The simulated CSOs used for the pilot were made up of a blend of screened and de-gritted primary influent and secondary plant effluent.

The results of this pilot study indicate that the planning design criteria for SOR supplied within the 2006 CSO Plan Update are too aggressive. The pilot plant outcomes are summarized in **Table 1.1.**

Table 1.1 – Pilot Study Outcomes

Issue	Performance Goal	Pilot Performance
CEPT vs. CEPT+plates	50 percent TSS removal continuous	• CEPT+plates consistently achieved 50% removal at loading rates 4 times CEPT alone • Pilot met performance goals at an SOR of 5,000 and 20,000 gpd/ ft^2 for CEPT and CEPT+plates, respectively

Issue	Performance Goal	Pilot Performance
Loading Rates	1.Identify SOR's based on gross area where requirements are met 2. Relate these SOR Rates to plate design	• The plates in this study increase the settling area of the CEPT clarifier tenfold, but yield a fourfold increase in SOR that results in meeting the project objectives. • *Example: A conventional clarifier with CEPT and 1,000 ft^2 could be expected to remove 50% TSS at a SOR of 5,000 gpd/ft^2 or a flow of 5 MGD. A CEPT+plates clarifier with the same gross surface area of 1,000 ft^2 but with a projected plate area of ten times the surface area could be expected to achieve the same performance at 20,000 gpd/ft^2 or 20 MGD; not ten times the capacity of the CEPT clarifier.*
Chemical Optimization	Define minimum dosages that meet the removal requirements at a wide range of SORs	• Effective PAX and Ferric chloride doses were 12 and 40 mg/L, respectively. These doses may be lower on real CSOs when the alkalinity is much lower than the blends used in the study.
UV Disinfection	Determine if an effluent can be produced with a low enough turbidity to make UV feasible?	• Yes, pilot plant effluent percent transmittance was similar to a normal secondary effluent. Based on the limited sampling in this study, UV should be effective in meeting the Fecal Coliform requirement of 400/100 mL currently in the CSO plant discharge permits at a relatively low UV dose.
Control, Operation and Maintenance	Identify major issues, if any, that will impact the design of a full scale facility	• Pilot showed reduced performance when sludge blanket was allowed to accumulate, due largely to the shallow depth of the pilot unit. The full-scale facility will require a deeper clarifier more typical of CSO facilities to avoid problems with sludge accumulation. • Loss of coagulant testing showed effluents from both sections began to degrade within approximately a half a detention time in the unit but recovered equally as fast after the coagulant was restarted.

Issue	Performance Goal	Pilot Performance
Removal of Conventional Pollutants, Metals and Organics	• COD • Phosphorus • Metals • Organics	• All composite samples showed removal of dissolved COD ranging between 27% and 54% for both CEPT and CEPT+plates at the effective SOR's. • Total P removal greater than 80% can be expected in optimized trials with either PAX or ferric chloride used as a coagulant. • Constituents that showed greater than 50% removal in both the CEPT and CEPT +plates include arsenic (both total and dissolved), copper, chromium, silver and lead. • There was significant reduction in PCBs associated with turbidity removal and some removal of Bis-Phthalate in a few trials.

The pilot project was successful in simulating CSO flows, treatment conditions and yielded results that can be used for full scale design.

1.2 Conclusions and Recommended Design Criteria

Based on the pilot testing results, recommended design criteria for CEPT and CEPT+plates for the CSO Control Program Update were developed. The recommend design criteria including limits for surface overflow rates and chemical dosing are contained in **Table 1.2**.

Table 1.2 Design Criteria

Recommended Design Criteria	Value	
	CEPT	CEPT + Plates
Surface Overflow Rate, gpd/ft²		
Achieve Greater than 50% Removal of TSS	5,000	20,000
Chemical Usage		
PAX Coagulant		
Dose, mg/L	12	12
Pounds per MGal Treated	100	100
Ferric Chloride Coagulant		
Dose, mg/L	40	40
Pounds per MGal Treated	330	330
Anionic Polymer Flocculent		
Dose, mg/L	1.5	1.5
Pounds of Polymer per MGal Treated	12	12
UV Disinfection		
Effluent Transmisivity (UV-254 nm), %	75	75

For CEPT and CEPT+plates, the design SOR is the maximum hydraulic loading rate per unit area that yields greater than 50 percent removal of the suspended solids. The SOR for CEPT is calculated using the entire surface of the clarifier. The SOR for CEPT+plates is somewhat more complex because the actual settling area is many times greater than the surface area of the clarifier due to the projected area of the plates. In the case of this pilot, the projected area of the plates was ten times the actual clarifier surface area. However, the piloting demonstrated equivalent performance for CEPT+plates at surface overflow rates only four times CEPT. This indicates that some inefficiency is present within the plate zone and the full projected area of the plates cannot be used for design.

The study found that the optimum dose for coagulant (PAX) and anionic polymer were 12 mg/L (as Al) and 1.5 mg/L, respectively. These dosages are consistent with other King County investigations of chemically enhance treatment on raw wastewater.

The limited results based on a single performance run for UV-254 absorption indicated the CEPT and CEPT+plates effluent had a tramsmisivity of approximately the same value. This value is also the same as many secondary effluents. UV should be a cost effective method for meeting water quality standards but more characterization is required.

1.3 Issues Not Resolved in the Pilot Testing

The dilution or the primary influent to simulate a CSO was made with secondary effluent resulting in a simulated CSO with a higher alkalinity than may characteristic of overflows along the Duwamish. Low alkalinity dilution water was not available at West Point. Jar tests conducted as part of this pilot and real operating experience at wet weather high rate treatment facilities indicate that the effective chemical dose on real, low alkalinity remote CSO will be lower than the optimum dose used in the pilot.

The pilot trials did not address some potential operational concerns when using plates in raw, unscreened wastewater. The pilot trials were after 5/8-inch screening and aerated grit removal at West Point. Future design efforts need to consider the need for fine screening and grit removal ahead of a full scale CEPT + plates installation to prevent plate plugging and minimize cleanup needs when a full scale system has completed treatment on a CSO event.

Section 2
Introduction

King County's Regional Wastewater Services Plan (RWSP) calls for development of satellite Combined Sewer Overflow (CSO) treatment facilities. The 5-year CSO program update from 2005 recommended that King County continue to monitor high rate treatment for potential consideration for CSOs at the King/Kingdome, Hanford/Lander, Brandon and Michigan sites. Likewise, the 2006 CSO Control Program Review recommended that pilot tests "be conducted on promising new CSO treatment technologies." The purpose of this project was to develop and implement a pilot test program to evaluate and compare potential CSO treatment technologies, assess whether or not the technologies are ready to meet County performance goals in full-scale CSO treatment facilities, and make recommendations based on that assessment.

This report presents the findings of the pilot testing and summarizes the pilot program. The report is organized into seven sections: Executive summary, Introduction, Pilot Facilities Configuration, Pilot Testing Protocol, Piloting Results, Summary and Interpretation of Results, and Scale-up Considerations.

2.1 Project Scope

The pilot project was conducted in two phases. Phase 1 focused on characterizing CSO treatment technologies, specific needs of King County related to CSO treatment, selecting a CSO treatment technology to pilot, and performing jar testing to evaluate polymer and coagulant performance. Phase 2 was the piloting work and included equipment selection, development of a pilot work plan and testing schedule, piloting and reporting.

This section summarizes the work done in Phase 1 and the Work Plan development from Phase 2. Details of how the Work Plan and Sampling Plan were utilized are summarized in Sections 3 through 7.

2.2 CSO Treatment Overview

Different approaches are being taken across the United States to effectively deal with reducing the discharge of untreated effluent associated with wet weather and combined collection systems. A great number of these use storage, but an increasing number of treatment facilities are being constructed. The answer to which technology/approach is the best depends on a multitude of factors. For example, in neighborhoods and in other areas where large land acquisition is not feasible, treatment in conjunction with storage provides a reasonable approach. Key issues that can impact design of such facilities include:

- Variability of design storm,
- Discharge permit requirements,
- Available and (footprint),

- Performance on trace constituents and emerging contaminants, and
- Solids thickening, storage, and removal.

For this project, TSS removal and disinfection have been the primary drivers regarding process selection. Conventional clarification and chlorination have served as the benchmarks while enhanced primary treatment technologies and UV are considered as still emerging technologies requiring further examination and practical operational history.

2.3 King County Specific Needs

This project was designed to provide additional data to support analysis of treatment alternatives for the county's four Duwamish CSO treatment projects (King/Kingdome, Brandon, Hanford/Lander, and South Michigan).

The State of Washington (WAC 173-245) established a technology-based and water quality-based approach to the treatment of CSOs as shown in **Table 2.1 and Table 2.2**.

Table 2.1 Summary of Performance Standards for Primary Treatment as applicable to King County CSO Facilities (Alki, Carkeek, Elliott West, MLK/Henderson)

Parameter	Standard[1]
TSS – Removal Efficiency	50 percent (yearly average)
Settleable Solids	1.9 mL/L/hr (Max per event) 0.3 mL/L/hr (yearly average)

Note – 1 Source is Department of Ecology Orange Book Standards

Table 2.2 Summary of Disinfection Standards for King County CSO Facilities (Alki, Carkeek, Elliott West, MLK/Henderson)

Facility	Fecal Coliform Bacteria /100mL[1]
Alki	400
Carkeek	400
Elliott West	400
MLK/Henderson	154

Note – 1 Source is NPDES Permit WA-002918-1

For the new CSO facility on the Duwamish Wasterway, TSS, settleable solids, pH and chlorine residual standards will be dictated by Ecology. Disinfection standards are assigned on a case by case basis depending on the outfall location and characteristics of the area (e.g. diffuser arrangement, depth, dilution effect, etc.) relating to the water quality in the given area. Current permit limits for county CSO facilities range from 154 to 400 fecal coliform bacteria per 100 mL as seen in **Table 2.2**.

Redundancy in the context of a CSO facility refers to critical facilities necessary to protect public health, safety and equipment. This would include components such as backup power systems, spare pumps, power supply, etc. CSO facilities are designed to operate intermittently. As a result, the main treatment equipment will not normally require redundant process tanks because there will be units (e.g. primary sedimentation units) not in operation during the majority of events.

To ensure performance of CSO facilities, NPDES permits require sampling and testing. A summary of the permit requirements for the existing facilities is provided in **Table 2.3.**

Table 2.3 Summary of Sampling Frequency for King County CSO Facilities (Alki, Carkeek, Elliott West, MLK/Henderson)

Facility	Source	Sample Type and Frequencyt[1]
Alki	NPDES Permit WA-002918-1	Flow proportional composit[2]
Carkeek	NPDES Permit WA-002918-1	Flow proportional composit[2]
Elliott West	NPDES Permit WA-002918-1	Flow proportional composit[2]
MLK/Henderson	NPDES Permit WA-002918-1	Flow proportional composit[2]

Note: 1 – A CSO event is considered ended after at least 24 hrs since last measured occurrence of discharge
2 – Series of individual samples collected over a flow period into a single container and represents the entire event. TSS percent removal is reported on a monthly basis. Temperature is tested twice per year

2.4 Process Overview and Selection

During Phase I, the team conducted an extensive review of the current CSO clarification technologies that could be successfully applied to King County and were appropriate for Phase 2 piloting. The technologies review included conventional primary clarification, chemically enhanced primary clarification, ballasted clarification, continuous deflective separation, hydrodynamic separation (vortex), and a salsnes filter. Of these technologies, only primary, chemically enhanced and ballasted clarification have been successfully applied to large-scale facilities for CSO treatment and were considered for application at West Point. The main drivers in the selection and review of the technologies were identifying technologies that would meet the regulatory standards, allow for a reduced treatment process foot print, and reduce construction costs.

The Project Work Plan completed during can be found in **Appendix A**. This document outlines all of the above mentioned technologies, benefits and drawbacks, and other considerations that impacted the selection of the technology to be piloted. For reference purposes **Table 2.4** (from the Project Work Plan) has been included to provide a summary of the clarification technologies and the advantages as well as limitations associated with each.

The Project Work Plan identified chemically enhanced clarification with and without lamella plates as the basis of the pilot. This pilot testing effort was designed to produce reliable data that can be used to support planning level decision processes on King County's future CSO treatment facilities.

During the development phase of the pilot project, the project team evaluated the feasibility of conducting pilot tests at a remote CSO site in order to have the ability to treat actual CSO events as they occur in the system. After examining the existing CSO facilities, the team determined that significant modification to existing facilities would be required in order to bring influent and effluent connections to the pilot unit. Further, the ability to conduct a pilot project on actual CSOs was not guaranteed due to the location of the pilot unit at a CSO facility and because CSO occurrences are weather dependent and not predictable.

Considering all of these factors, the project team elected to conduct piloting operations at West Point Wastewater Treatment Plant. The pilot unit was located adjacent to the county's pilot test facility allowing for easy access to various plant process waters, electrical connections and a wet well to return effluent to the treatment plant. Additionally, locating the pilot at West Point enhanced the ability of the pilot operators to react to a CSO event in a timely manner and under controlled conditions. A blending tank with primary influent and dilution water served as a surrogate CSO source and allowed pilot testing even when actual CSO events were not occurring. The configuration of the blend tank and blending parameters are covered in detail in Section 3.

Table 2.4 Update Technology Summary Clarification Technologies for Intermittent Wet Weather Treatment

Technology	Advantages relative to Primary Treatment	Disadvantages relative to Primary Treatment	Relative Footprint to Achieve 50% TSS Removal	Relative Capital Costs	Relative Annual O&M Costs	Estimated Removal Rates (%)				Operations and Maintenance Considerations (including odor)	Questions pilot scale testing would address	Other opportunities/locations to collect similar information
			Preliminary Site Plans for alternatives found in **Appendix A**			TSS[1]	BOD/ COD[1]	Organics	Metals			
Conventional Primary Clarification	• Base Case • Well known technology SOR (1 to 3 gpm/ft²)			Low	Low	50 to 70%	25 to 40%	25 to 40%	30 to 40%	Large basins will require additional clean-up time	• Address problems/feasibility of in basin chlorination application	• Carkeek, Alki CSO facilities
Chemically Enhanced Primary	• Higher SOR (10 to 30 gpm/ft²)	• Greater chemical storage and application requirements	• About 10% reduction in site requirements	Medium	Medium	70 to 90%	35 to 50%	35 to 40%	35 to 40%	Increase chemical storage and chemical deliveries	• Determine variability in CEPT effluent with respect to turbidity and transmisivity as well as chlorine effectiveness • Maximum SOR while achieving >50% TSS reduction	NA
Ballasted Clarification	• Higher SOR (20 to 40 gpm/ft²)	• Some technologies may have long start-up times (Densadeg)	• About 30% reduction in site requirements	High	Medium	80 to 94%	50 to 75%	50 to 75%	50 to 65%	Same as Chemically Enhanced Primary	• Determine feasibility of chemical addition/supplement to lower power/O&M cost • Evaluate O&M concerns regarding Actiflo • Investigate SOR for this approach at remote locations & sludge start-up issues	• Bremerton Eastside operating successfully for six wet seasons • Three other end of pipe plants by 2008 (Salem OR, Cincinnati OH, Nassau NH) • Karcher Creek SD (KCSD) plant available for testing full scale • Densadeg: three SSO plants operating since 2006 o Shreveport (2 @ 20 mgd) o Toledo (175 mgd)
Bio-enhanced Ballasted Clarification	• Full secondary equivalent could be achieved during overflows SOR (20 to 40 gpm/ft²)	• More complicated operation	• About 30% reduction in site requirements	High	High	97 to 99%	85 to 90%	50 to 80%	50 to 75%	Same as Chemically Enhanced Primary Solids line flushing required	• Address adding active biomass at remote location and start-up concerns (i.e. trucking or collecting from collection system) • Address O&M issues using this approach	• Karcher Creek SD (KCSD) plant available for testing full scale
Hydrodynamic Separation (Vortex)	• Simple operation SOR(30 gpm/ft²)	• Cannot meet removal efficiency	• Cannot meet this standard with this approach alone	Low	Low	10 to 35%	15%	>25%	NA	Would require extensive and continuous cleaning to maintain removal rates	• Review suitability as pretreatment for other technologies • Evaluate metal removal capability • Evaluate chemical addition	• Columbus, GA installations
Continuous Deflective Separation (CDS)	• Simple operation SOR (30 gpm/ft²)	• Cannot meet removal efficiency	• Cannot meet this standard with this approach alone	Low	Low	10 to 45%	15% to 20%	>25%	NA	Would require extensive and continuous cleaning to maintain removal rates	• Review suitability as pretreatment for other technologies • Evaluate metal removal capability	• Scott Wells, PSU performed removal efficiency testing on these • Minneapolis Park and Recreation Board installations
Salsnes Filter	• Potentially smaller site lay out	• Complex piping arrangement	• NA	Medium	Low	40 to 70%	30 to 40%	NA	NA	Cleaning requirements	• Suitability as pretreatment for other technologies • O&M required for CSO use • What size screen would improve performance • Metal removal efficiency	• A few installations in Canada
Electro Coagulation	• Less chemical addition • Effective removal of Oil and Grease	• Never been done in a wet weather treatment application	• Same as A2 (still requires use of clarifiers)	Unknown	High	50 to 70%	30 to 40%	<50%	Unknown	High energy requirements for large installations	• Evaluate effectiveness on CSO quality influent • O&M required for CSO use • Develop design information for estimating capital costs	• Pacific Fisherman Shipyard • City of Redmond BMP's

Note 1 – TSS and BOD/COD removal is soluble and influent dependent.

Table 2.4 Update Technology Summary (cont.) Add-On Technologies for Intermittent Wet Weather Treatment

Technology	Advantages relative to Primary Treatment	Limitations relative to Primary Treatment	Relative Footprint to Achieve 50% TSS removal	Relative Capital Costs	Relative Annual O&M Costs	Estimated Removal Rates (%)	Operations and Maintenance Considerations (including odor)	Questions pilot scale testing would address	Other opportunities/locations to collect similar information
Lamella plates	Higher SOR (20 to 40 gpm/ft²)	Cleaning	NA	Low	High (labor)	• 10 to 20 %	• Effectiveness of the lamella plates in a high rate CEPT • Investigate startup and lamella plate issues	• Plugging/Fouling	NA
Compressed Media Filter (Fuzzy Filters)	Compact size and higher SOR (15 gpm/ft²)	Cleaning and reliability	NA	Medium	Medium	• 15 to 20%	• Backwashing during an event • High Loads	• Effectiveness paired with other technology	One new operating facility in Georgia
Dissolved Air Flotation	High FOG removal	O&M issues, reliability at other installations	NA	Medium	Low	• 20%	• Scum and Solids handling	• Chemical conditioning for dilute sewer flows	NA
Membrane filtration	High removal efficiencies	Low SOR	NA	High	High	• 25 to 30 %	• Control and screening requirements	• O&M concerns for remote and periodic start-ups • Peaking factors • Fouling potential	Full scale performance data

Disinfection Technologies

Technology	Advantages Relative to Hypochlorite	Limitations Relative to Hypochlorite	Relative Footprint	Relative Capital Costs	Relative O&M Costs	Effectiveness	Operations and Maintenance Considerations	Questions pilot scale testing would address	Are there other opportunities/locations to collect similar information?
Hypochlorite	Base Case							• Chlorine dose points and dechlorination strategies	• Carkeek, Alki CSO facilities
Hypochlorite addition early in treatment process (i.e., in basin)	• Longer contact time		Elimination of additional contact tank	Low	Medium	NA	NA	• Effectiveness compared to base case	• EBMUD
UV	• No dechlorination • Short contact time	• Need good quality influent to process	60 to 70% reduction in size	High	Medium	Capable of 4 log reduction in fecal coliform	Lamp fouling and ballast concerns Dependent on TSS power	• Develop data base on toxics and transmisivity	• Bremerton Eastside • Columbus, GA installation • Shreveport installations
UV with hydrogen peroxide addition	• Effective at destruction of trace organics in clean water	• Same as C3	50% reduction in size (requires chemical storage)	High	High	Capable of 4 log reduction in fecal coliform	Same as C3 Chemical storage and application issues	• Effectiveness on treated CSO quality influent	• Orange County, CA (CDM design)
Bromide	• NA	• NA	NA	Medium	High	NA	NA	• NA	• NA
Parecetic acid	• No disinfection by-products formed • Long shelf life	• NA	NA	Medium	High	NA	NA	• Effectiveness when paired with UV	• Columbus, GA installation • Shreveport installations
Chlorine Dioxide	• Greater disinfection power • Less disinfection by-products formed	• Inconsistent results on high TSS effluent	Same	Medium	Medium	Superior inactivation of protozoan cysts	NA	• Effectiveness compared to base case	• NA

2.5 Description of Enhanced Clarification Technologies

Chemically-enhanced primary clarification or treatment (CEPT) is a physical-chemical process that utilizes chemical addition before conventional primary clarifiers to enhance removal of TSS, biochemical oxygen demand (BOD), particulate nitrogen and phosphorus, and phosphate. Traditionally the CEPT process is carried out with the use of metal salts and/or polymers in the form of organic polyelectrolytes. Typical chemical coagulants include iron salts (ferric and ferrous chloride); although, aluminum salts (alum and polyaluminum chloride) can also be used. Anionic polymers are the most common flocculants used.

During CEPT, a chemical coagulant is added to the wastewater upstream of the primary clarifiers. This encourages destabilization of the colloid particles in the wastewater so that particle growth can occur by the mechanism of adsorption and particle collision aided by the addition of mixing energy. A flocculent aid (polymer) is added after the coagulant injection and serves to aid in particle collision and provide bridging action. The chemical addition causes the suspended particles to clump together resulting in particles with higher settling velocities, which increases their removal rate and enhances treatment efficiency.

Figure 2.1 shows a typical configuration for when CEPT is retrofitted to an existing plant, as was done at the Hyperion Wastewater Treatment Plant (413 MGD design average flow) in Los Angeles, CA. At Hyperion, $FeCl_3$ is injected upstream of the headworks and polymer is added downstream of the aerated grit chambers in the primary clarifier influent channels. At other plants, polymer is added directly to the inlet zone of the primary clarifiers.

Figure 2.1 Typical CEPT Retrofit Configuration at Existing Wastewater Treatment Plant: Chemical Injection without Rapid Mix/Flocculation Tanks (Hyperion Wastewater Treatment Plant; LA DPW & DWP 2006)

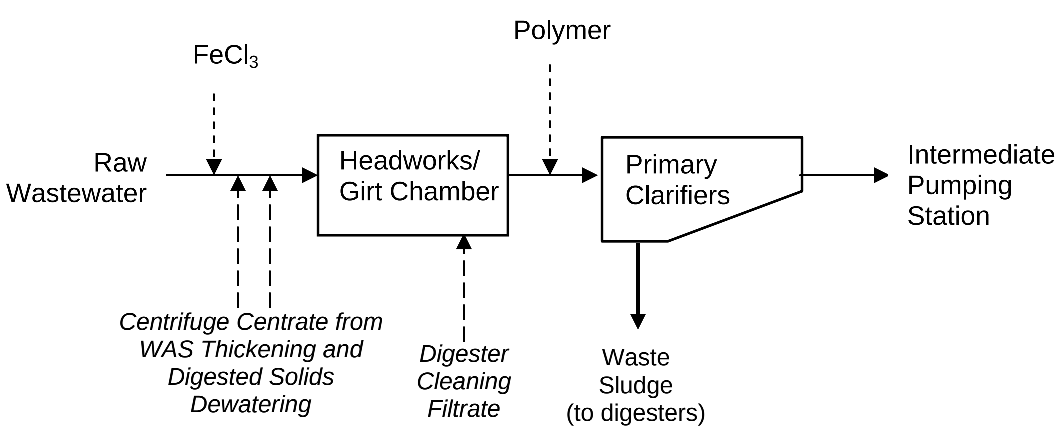
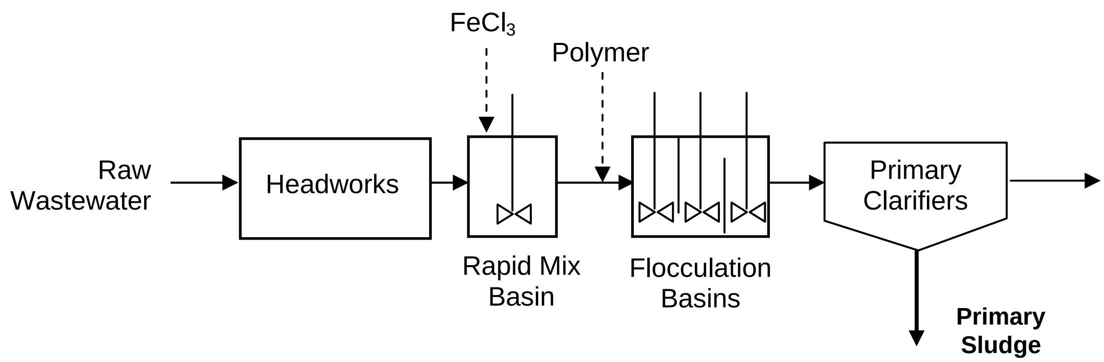


Figure 2.2 shows a typical configuration for CEPT with external flocculation tanks, as were installed at the new facilities at the R.L Sutton Water Reclamation Facility (40mgd design average flow) in Cobb County, GA. Addition of external flocculation

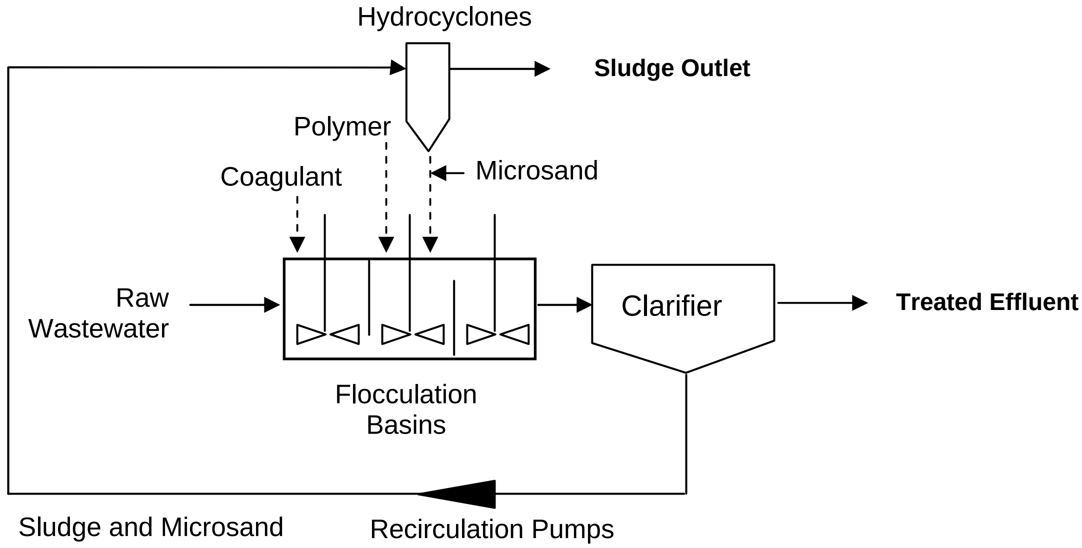
tanks (i.e., steel tanks) was common in US plants built in the 1930s. Operating experiences at full scale CEPT facilities indicate that detention time and flocculation in the distribution piping to the clarifier and the clarifier inlet baffling is usually adequate. Flocculent and coagulants can be added far upstream of the clarifiers as shown in **Figure 2.1**.

Figure 2.2 Typical CEPT New Facility Configuration: Chemical Injection into Rapid Mix and Flocculation Tanks (R.L. Sutton Water Reclamation Facility; Mills *et al.* 2006)



To increase the efficiency of the CEPT process, another approach has been to introduce a ballasting agent. Typically microsand or sludge is added to the floc prior to clarification. This process is commonly referred to as High Rate Clarification (HRC). The ballast greatly increases the particle decent rate by increasing the particle density, The increase causes a greater amount of material (typically expressed in TSS) to be removed. With this treatment approach it is possible to remove greater than 70% of TSS, 50% of BOD, and a much higher surface overflow rate (SOR) than primary or chemically enhanced clarification alone. **Figure 2.3** outlines a typical ballasted configuration featuring microsand as the ballasting agent.

Figure 2.3 Typical Ballasted Configuration: Microsand Approach



2.6 Critical Design Parameters

Factors that influence the design of chemically enhanced primary clarifiers are discussed in this section. Factors include solids settling velocity, SOR, horizontal projected surface area for plate settlers, and chemical dosing strategy.

2.6.1 Settling Velocities and Surface Overflow Rates

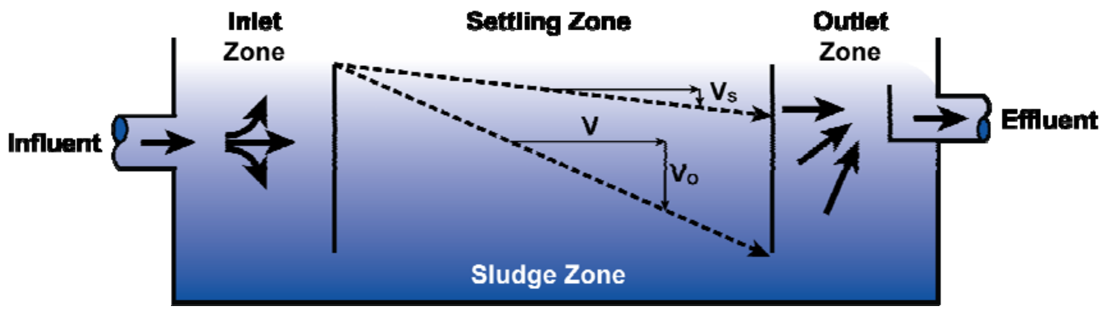
Sedimentation is one of the key processes of solids removal from wastewater. Solid particles that are denser than water fall out of solution via gravity. Suspensions in raw wastewater are comprised of particles of all different shapes, sizes, densities and settling characteristics.

The design of primary clarifiers and CSO treatment units relies on the use of discrete and flocculent particle settling concepts to remove suspended solids. The particle to be removed has an associated vertical velocity, settling velocity or terminal velocity shown as $\mathbf{v_s}$. As shown in **Figure 2.4**, a sedimentation tank has a design velocity or an ideal overflow rate $\mathbf{v_O}$. As long as $\mathbf{v_S}$ is greater or equal to $\mathbf{v_O}$, the particle will be settled and removed. Particles also coalesce during sedimentation, which can cause $\mathbf{v_s}$ to increase. This type of settling is known as flocculent settling. The suspended solids removal that occurs in a CSO clarifier is a combination of both types of settling.

As the flow rate and the horizontal velocity in the clarifier increases, the detention time in the clarifier decreases and fewer particles are removed. Additionally, at high horizontal velocities, settled solids can be scoured off the bottom and carried out in the effluent, thereby reducing removal rates.

During the design phase, the design settling velocity or overflow rate will have to be adjusted for the effects of inlet and outlet configurations, wall effects, temperature, wind, short circuiting, sludge storage, and velocity gradients due to sludge removal equipment operating in relation to the length of the settling basin to ensure that the settling velocity requirement is met.

Figure 2.4 Discrete Particle Settling



For design purposes, V_O=Q/A can also be expressed in units of flow divided by the sedimentation tank's surface area or SOR (typically gpd/ft^2 or gpm/ft^2). Most SORs reported in this study are in gpd/ft^2.

Where:

V= The horizontal velocity of flow in the tank =ft/sec

Vs= The vertical settling velocity of a particle =ft/sec

V_O= Ideal sedimentation settling velocity or SOR, (ft^3/sec/ft^2) =ft/sec

Q=Flow to the sedimentation basin, (ft^3/sec)

A=Surface area of sedimentation basin, (ft^2)

Most primary clarifiers are able to remove 30 to 40 percent of BOD_5 and 50 to 70 percent of TSS on raw wastewater. Currently, the Washington State Department of Ecology (DOE) has recommended standards on average design and peak day SORs for traditional clarification of 1,000 and 2,500 gpm/ft^2 respectively, and requires pilot, or similar, testing for chemically enhanced primary clarification for CSO treatment. In the absence of such data, a peak hourly overflow rate of 4,000 gpd/ft^2 for the once-per-year design storm is recommended.

2.6.2 Plate Settlers

Plate settlers, tube settlers and lamella clarifiers (all referred to plates in this study) have been used in drinking water treatment but have also gained acceptance in wastewater treatment, specifically for the high-rate clarification process (Krueger

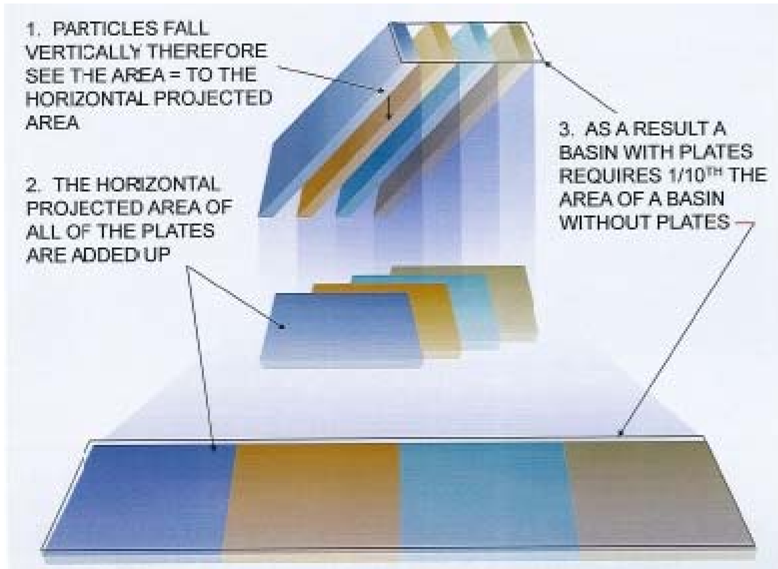
Actiflo and IDI Densedeg). Plants with plate or lamella separators on raw sewage are generally preceded by effective fine screening with an opening of ¼-inch or less. The plate configuration includes horizontal plates, steeply inclined plates or steeply inclined tubes with flow entering in from the bottom and exiting the top over a weir. The version used in this pilot study uses plates inclined at a 55 degree angle with cross-current flow entry.

The cross-current flow entry method reduces the likelihood of distributing solid material settling in the plates. As the wastewater flows up the plates, solids settle on the inclined portion. The general principal is that the material falling out of solution does not have to travel far before it is out of the flow stream and part of the clarifier floor boundary (i.e. the physical distance between the plates, instead from the top of the clarifier to the bottom layer). In essence, the plates or tubes act like multiple mini-clarifiers inside a single clarifier unit.

The discussion of settling velocities in the previous section applies to plates. The distance suspended solids need to fall in a plate clarifier to be out of the wastewater is much less than a conventional clarifier. **Figure 2-5** outlines the typical configuration for a plate or lamella clarifier. For the purposes of this study, the terms plates and lamella plates will be used interchangeably. Lamella implies a thin plate and is typically used in water treatment where the plates are thin, close together and not subject to the plugging and fouling seen in wastewater.

In horizontal plates, sludge remains on the plates and is washed out at the end of the run. For steeply inclined plates, which are shown in the **Figure 2-5** and were used in this study, the sludge continuously falls out of the bottom of the plates and accumulates in the bottom of the clarifier tank. As the velocity of flow up the plates increase to extreme values, sludge does not settle from the plates and any suspended solids that enter the plate zone are swept out into the effluent. At that point, the lamella plates act more like baffles to create stable hydraulic conditions throughout the entire clarifier but are not adding settling area to the clarifier.

Figure 2.5 Horizontal Projected Area for a Plate Settler (Courtesy of MRI)



Ten States Standards for Water Treatment plant design suggest the following method for calculating the effective settling area for plate or lamella settlers:

> Horizontal Projected Surface Area = (length x width of each plate) x cosine 55 degrees x Ten States Standards Efficiency Factor x Number of Plates

Substituting numbers, the equation takes the form:

> Horizontal Projected Surface area = (Length x Width) x 0.574 x 0.8 x Number of plates = 0.46 x Individual Plate Area x Number of plates

The plates used in this study are at 55 degrees from horizontal as detailed in Section 3 – Pilot Facilities Description and had the following characteristics:

- Plate Dimensions = 4.5 ft wide by 4.5 ft tall
- Angle from horizontal = 55 degrees
- Number of plates = 7
- Ten States Efficiency Factor = 80%
- Horizontal Projected Surface area = 65 ft^2
- Gross Clarifier Surface area = 6.8 ft^2 (actual surface area of clarifier occupied by plates)
- Ratio of Horizontal Projected Surface Area to Surface area = 65/6.8 = 10

The lamella plate clarifier section in this study has 10 times the effective area as the clarifier surface alone. In this report, the SOR will be reported based on both the gross clarifier surface area and the horizontal projected plate area. For the purpose of this pilot, the primary settling zone (CEPT) ranges from 1,400 to 9,600 gpd/ft^2 (gross clarifier surface area). Similarly, the plate zone ranged from 5,000 to 43,000 gpd/ft^2 (gross clarifier surface area) or 500 to 4500 gpd/ft^2 (horizontal projected plate area).

2.6.3 General Chemical Dosing Strategies

CSO treatment facilities have been designed to use both flow and turbidity to set chemical dosing rates. Flow pacing for chemical addition is a well-established method that utilizes a parshall flume, magnetic flow meter, or other flow measurement device and correlates with the chemical injection system. Typically, a programmable logic controller will be programmed to automatically adjust for flow conditions. The dosage will be based on jar testing or field trials that prove successful.

Turbidity paced chemical addition is possible, but these devices have proven to be unreliable in some existing full-scale installations. In limited use facility these devices have a tendency to plug up and require additional O&M time to maintain this portion of the system. This will be compounded if screening or grit removal is not incorporated in upstream pretreatment since field turbidity meters take a snapshot in time and debris blowby can cause false readings requiring greater chemical demand than is actually needed. For future full-scale installations, flow paced chemical addition would be the preferred alternative

With ether type of chemical dosing strategy, proper mixing and floc development time is crucial for proper performance. Ten States Standards suggest a minimum of 30 seconds for flash mixing when separate basins or structures are feasible. Additionally, Orange Book suggests velocities not to exceed 0.5 fps to avoid shearing floc in flocculation/maturation zone.

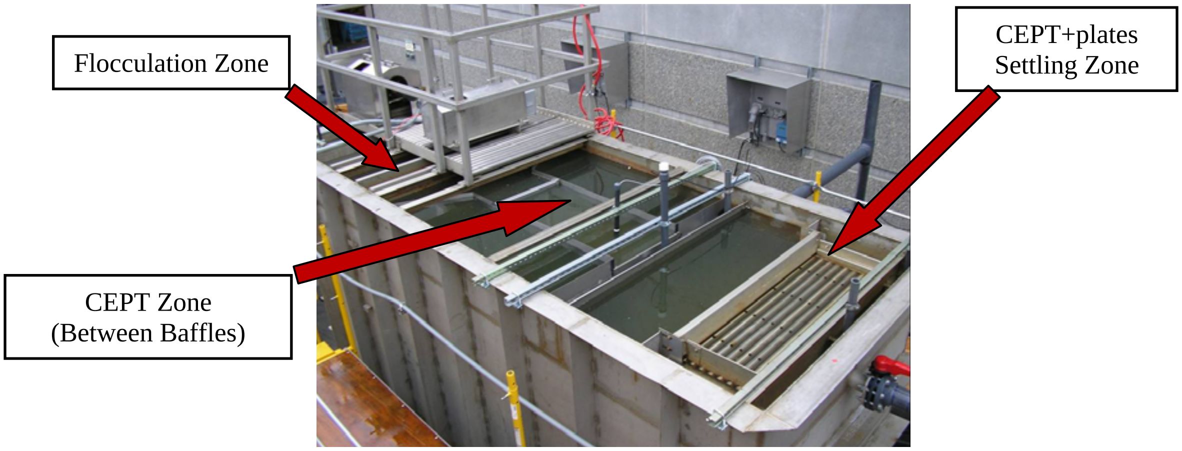
Section 3 Pilot Facilities Configuration

The pilot system is a self-contained unit equipped to operate as a scaled-down version of a chemical enhanced primary clarifier. Upstream of the clarification areas (sedimentation zones), a 3-stage chemical conditioning (flocculation) stage was incorporated with the required tanks, chemical metering pumps, instrumentation and controls. The pilot system was equipped with two different feeds. One feed consisted West Point primary influent (PI) that had been screened (5/8-inch opening) and treated with grit removal via an aerated grit basin. The second feed consisted of a blend of the screened and degritted PI and chlorinated secondary effluent (C3) from West Point. Different feeds were used depending on the trial run configuration.

In the initial conversations with the pilot unit supplier, the team proposed to have two pilot units operating side by side. Pilot unit 1 would have consisted of a primary settling zone with plates for CEPT+plates testing, while pilot unit 2 would have consisted of a primary settling zone only for CEPT testing. However, two full units would have required more PI and C3 than the pilot area infrastructure at West Point could provide and would have resulted in two parallel chemical conditioning systems. Flocculation would have been different for each process train making a true comparison of the technology and validation of findings with other pilot studies difficult.

The final approach incorporated both the CEPT and CEPT+plates settling zones into a single unit with a parallel configuration. This configuration reduced the total flow needed for the study, simplified the flow and chemical dose control, and allowed for simultaneous operation of the two units. To validate the refined approach and ensure the two settling zones acted independently of one another, the pilot unit effluent discharge from both the CEPT and the CEPT+plates settling zones was characterized by dye testing and compared to existing primary performance at West Point. These topics are covered in greater detail in **Sections 4.1** and **4.2**, respectively.
Photograph 3.1 shows the configuration, and various zones of the pilot unit. More comprehensive information pertaining to the function of each zone will be discussed in greater detail in this section.

Photograph 3.1 Pilot Unit Components (without flow)



A plan and section view of the pilot unit, as provided by the manufacturer has also been included in **Figure 3.1** for reference.

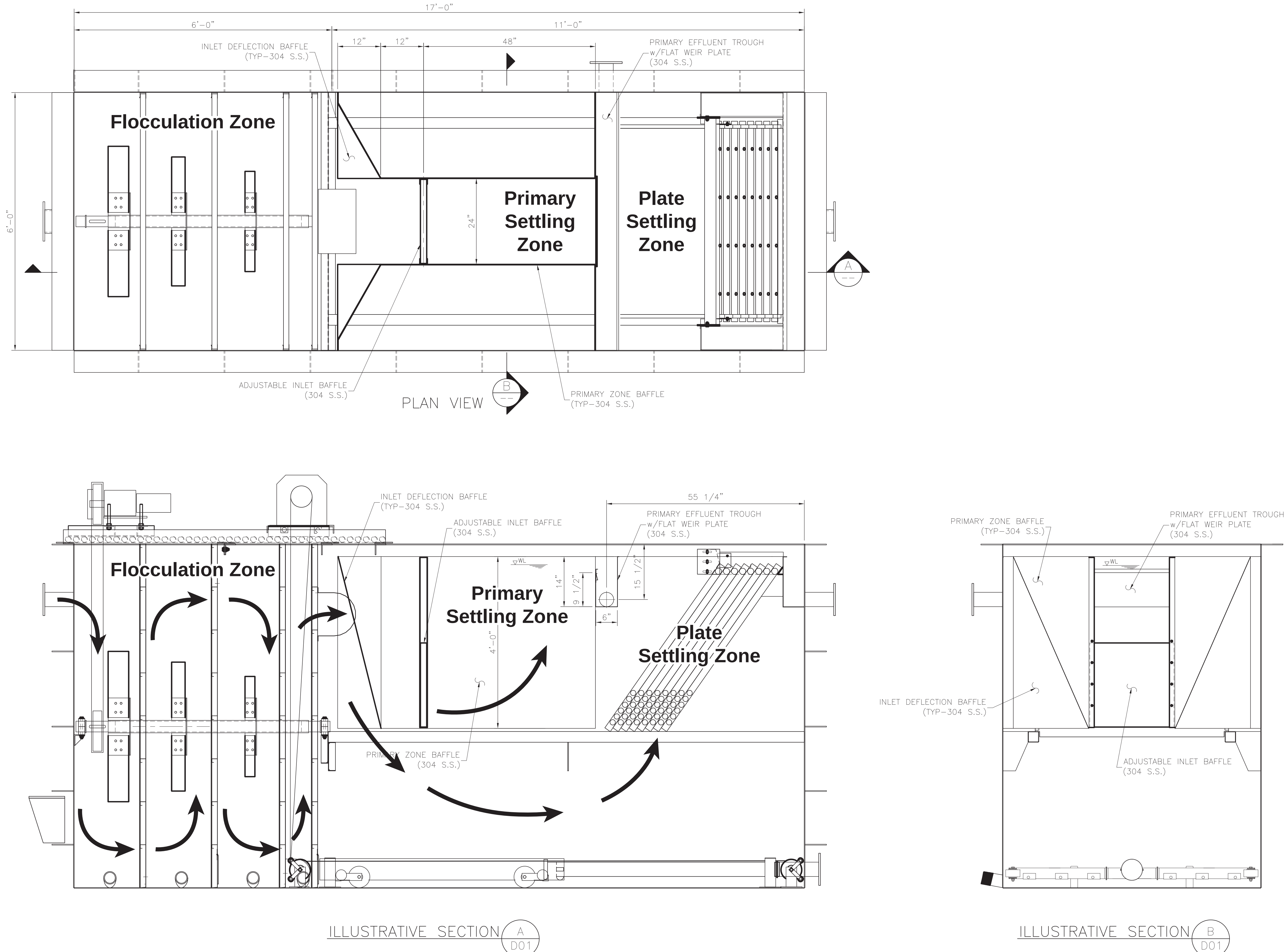


Figure 3.1 - Pilot Unit

MEURER RESEARCH, INC. 15611 W. 6th Ave., Golden, CO 80401	PROJECT NAME: King County CSO Pilot PROJECT LOCATION: King County, WA	DRAWN BY: CDH DATE: 10-6-08	General Assembly Plate Settler Pilot Unit	This drawing and the contents thereof are the property of Meurer research Inc. and may not be copied without the consent of Meurer Research, Inc.. This drawing may not be used in any way that would be detrimental to the aforementioned.	DRAWING NUMBER D01

3.1 Clarifier

The pilot clarifier system included a flocculation zone and a dual sedimentation/settling zone. The dual sedimentation zone included a primary settling zone for CEPT testing, and a primary zone with plates for CEPT+plates. The two zones were configured in parallel to allow simultaneous operation. Specifics regarding each zone are discussed below.

3.1.1 Flocculation

The 3-stage flocculation unit common to the CEPT and CEPT+plates was installed upstream of sedimentation units. The flocculation unit consisted of 3 tanks operated in series with chemical metering pumps, mixing units, instrumentation and controls. Each tank had an independent mixing unit with a variable speed motor that allowed for manual speed adjustment of the flocculator paddles. Actual operations of the pilot unit did not use the variable speed mixing feature based on previous pilot experience and recommendations from the equipment manufacturer. The flocculator mixing paddles were set at a constant speed.

Each stage of the flocculator was separated by a stainless steel baffle wall with openings that created an over and under flow pattern. The over and under flow pattern has been drawn in on **Figure 3.1** for reference.

Mixing energies used within the flocculation zones were determined based on jar tests and recommendations from the manufacturer. The parameters of the flocculation stages, including their respective mixing energy G-values are contained in **Table 3.1.**

Table 3.1 Flocculation Zone Parameters

Stage	Stage Volume	Impeller Dimensions (Length x Width)	G-Value sec^{-1}	Hydraulic Detention Time	
				Max Flow Rate	Min Flow Rate
First	75 ft^3	3.5 ft x 0.5 ft	69	7 minutes	43 minutes
Second	75 ft^3	3.0 ft x 0.33 ft	39		
Third	75 ft^3	2.3 ft x 0.25 ft	20.5		

Discharge from the flocculation zone was via a submerged baffle. The submerged baffle provided a means of evenly distributing the flow to the sedimentation zones, and minimized short-circuiting and turbulence that could have influenced the efficiency of the sedimentation zones.

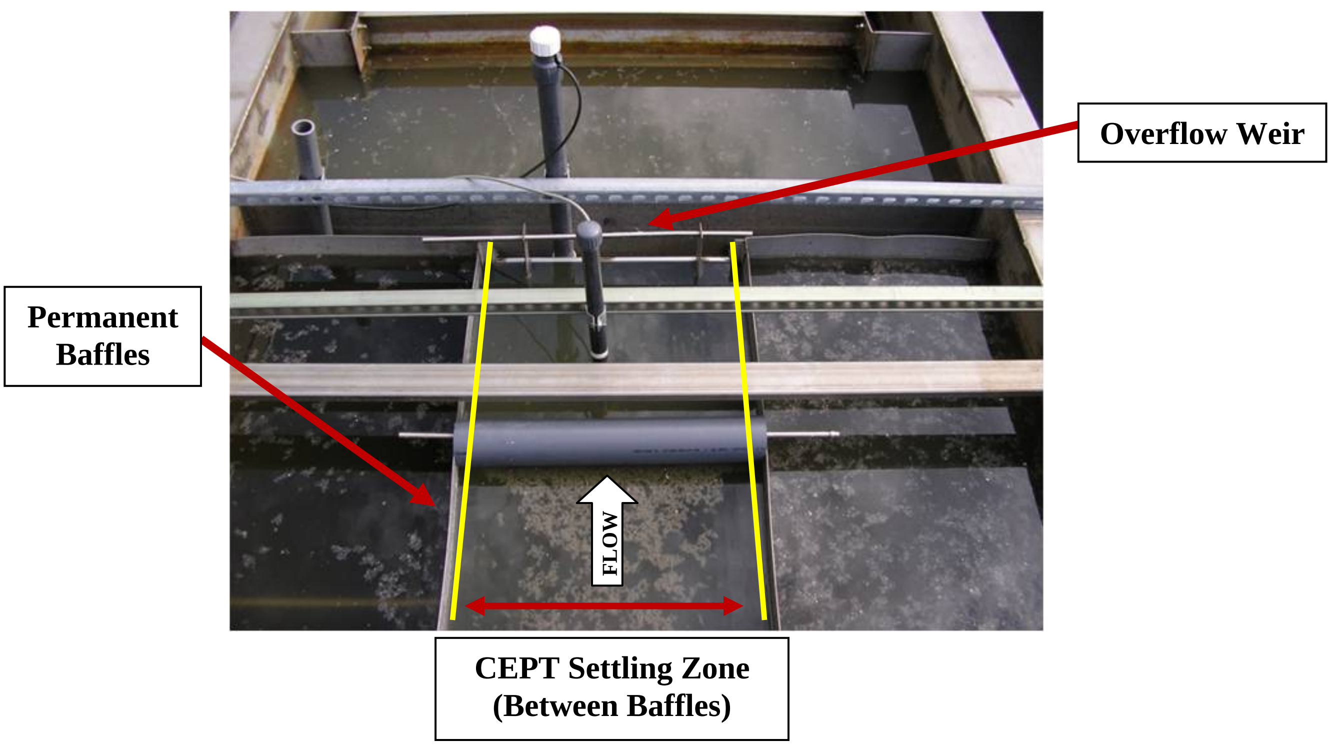
3.1.2 Sedimentation Zone

A dual sedimentation zone with and without plates was included in the pilot to compare the performance of CEPT and CEPT+plates. The first zone without plates was configured like a conventional primary clarifier and facilitated comparison to the existing clarifiers at West Point.

3.1.2.1 CEPT

The sedimentation zone without plates was used for tests on conventional CEPT. The CEPT sedimentation zone was designed with two permanent stainless steel baffles that extended from the nominal water surface elevation to four feet below the water line and an adjustable primary weir. The baffles created a settling zone with a surface area of 10 ft^2 and an active volume of 54 ft^3 within the settling tank. These dimensions of the CEPT settling zone and the adjustable weir level allowed the project team to operate the CEPT system at the desired SORs. **Photograph 3.2** illustrates the baffling arrangement utilized during the course of piloting.

Photograph 3.2 CEPT Settling Zone



A table documenting the dimensions of the CEPT sedimentation zone has been provided in **Table 3.2.**

Table 3.2 CEPT Sedimentation Zone Parameters

Parameter	Pilot Testing Min	Pilot Testing Max	Full-Scale Typical
Loading Information			
Flow Rate (gpm)	8	68	---
Hydraulic Loading Rate (gpm/ft^2)	0.8	7	1.4 to 2.1
Hydraulic Loading Rate (gpd/ft^2)	1,150	9,600	2,016 to 3,024
Weir Loading Rate (gal/day*ft)	560	1,950	10,000 to 40,000
Hydraulic Residence Time (minutes)	7	27	---
Dimensions			
Length (ft)	5		Length to width ratios of 4:1 to 5:1
Width (ft)	2		
Depth (ft)	5.4		8 to 20
Clarifier Surface Area (ft^2)	10		---
Volume (ft^3)	54		---
Weir Length (ft)	2		---

It should be noted, that the CEPT sedimentation zone originally had an adjustable baffle at the inlet to help distribute flow in the settling zone. However, during dye testing it was observed that the adjustable baffle was actually impacting flow distribution through the pilot unit. Subsequent dye test runs without the baffle proved a more predictable plug flow arrangement and the project team elected to remove the adjustable baffle from future piloting trials.

3.1.2.2 CEPT with Plates

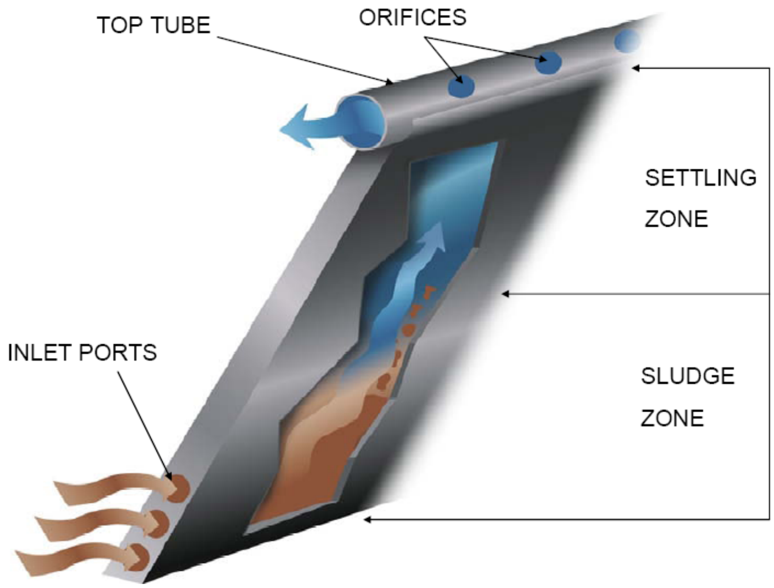
The CEPT+plates sedimentation zone was configured with seven plates to achieve the desired surface overflow rate (SOR) for pilot testing. Typically, this unit would have been equipped with 24 plates, however to fit within the project area, to meet the flow conditions and availability at West Post, and to operate the unit at an SOR consistent with full-scale plate applications, the number of plates was reduced to seven. Seven active plates correspond to a water surface area of 6.8 ft2. A photograph of the CEPT+plates settling zone is provided in **Photograph 3.3**.

Photograph 3.3 Plate Configuration

It is important to note that only seven out of the eight plates shown in **Photograph 3.3** are effective plates. The eighth plate is not effective and included in operational performance due to a limitation in the effluent collection mounting system, which eliminated the performance of this plate.

Figure 3.2 has been included to illustrate how an individual plate receives and treats flow. Each plate features inlet ports located at the bottom of both sides of the plate. Flow enters at the bottom and progresses up the length of the plate with flow exiting between adjacent plates. As flow travels up, particles collect and settle out on the plate and are removed below. The clarified flow enters the orifices of the effluent collection system at the top of the plate and is passed on for subsequent disinfection and discharge.

Figure 3.2 Plate Cross-Section



A table documenting the dimensions of the CEPT+plates sedimentation zone has been provided in **Table 3.3.**

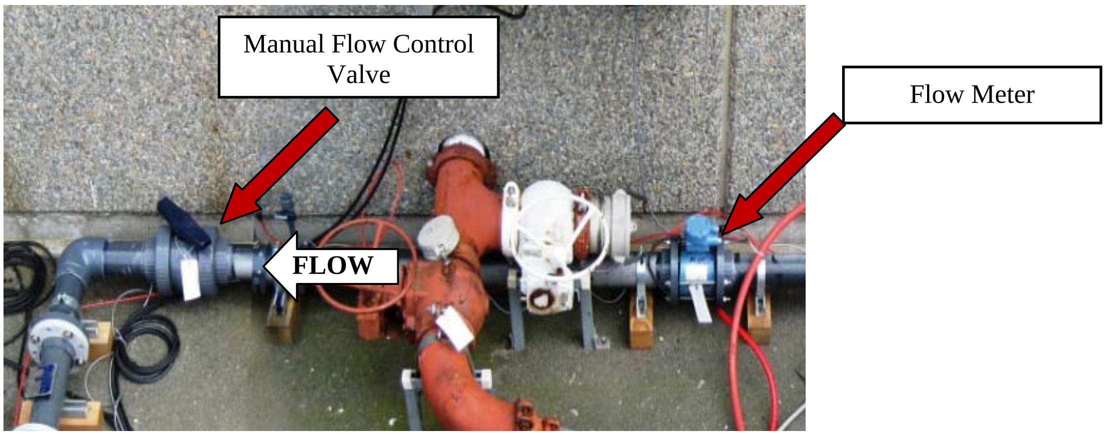
Table 3.3 CEPT+ Plates Sedimentation Zone Parameters

	Pilot Testing Min	Pilot Testing Max	Full-Scale Typical
Loading Information			
Flow Rate (gpm)	30	205	---
Hydraulic Loading Rate (gpm/ft^2)	4.4	30	10 to 40
Hydraulic Loading Rate (gpd/ft^2)	6,300	43,400	14,400 to 57,600
Plate Loading Rate (gpm/ft^2)	0.3	3.2	---
Weir Loading Rate (gal/day*ft)	2,100	13,000	10,000 to 40,000
Hydraulic Residence Time (minutes)	11	60	---
Dimensions			
Length (ft)	1.75		Length to width ratios of 4:1 to 5:1
Width (ft)	4.5		
Depth (ft)	4.5		8 to 18
Clarifier Surface Area (ft^2)	6.8		---
Volume (ft^3)	31		---
Weir Length (ft)	3		---
Number of Plates	7		80% of clarifier surface area
Projected Plate Area (ft^2)	65		

3.2 Flow Control

Flow to the pilot unit was controlled in two ways: a manual flow control valve and an adjustable weir within the sedimentation tank. The manual flow control valve is shown in **Photograph 3.4**. An operator would set the position of the ball valve to produce the desired flow from the blending tank to the pilot unit as indicated on the flow meter.

Photograph 3.4 Manual Flow Control Valve



Flow from the blending tank to the pilot unit was provided by a 5 hp submersible pump. A recirculation line from the submersible pump was also incorporated into the design to ensure that solids were kept in suspension in the blend tank and that a homogenous feed was delivered to the pilot unit. An overflow line in the blend tank that went directly to drain was provided so that a fresh blend could be continuously introduced and to ensure a safe discharge of the CSO blend surrogate when the flow to the pilot unit was low. A process schematic is of the pilot feed is provided in **Figure 3.3.**

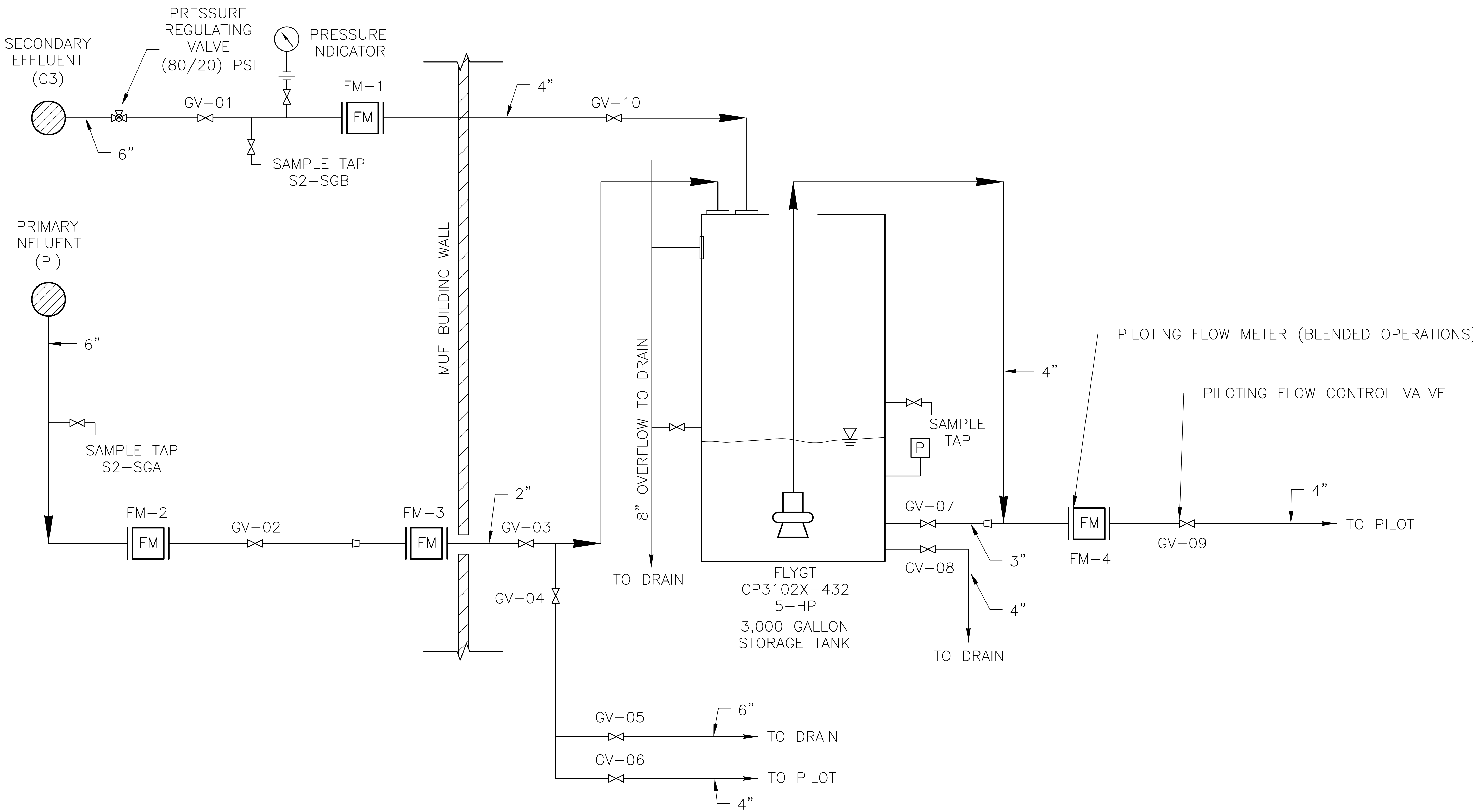
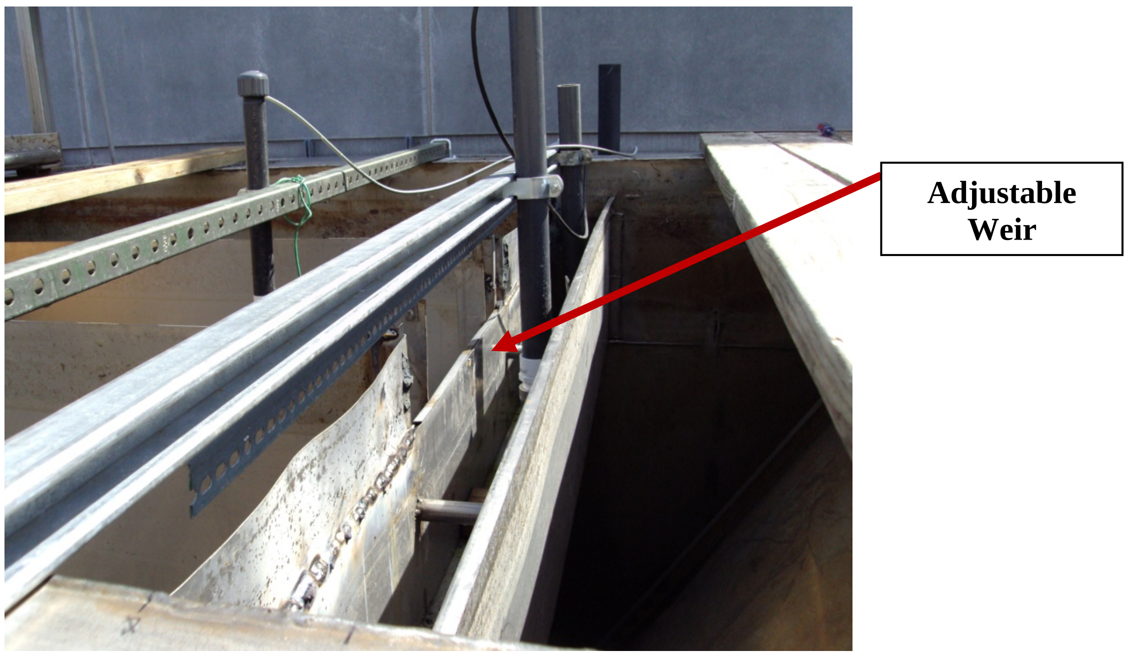


FIGURE 3.3
BLENDING PROCESS SCHEMATIC

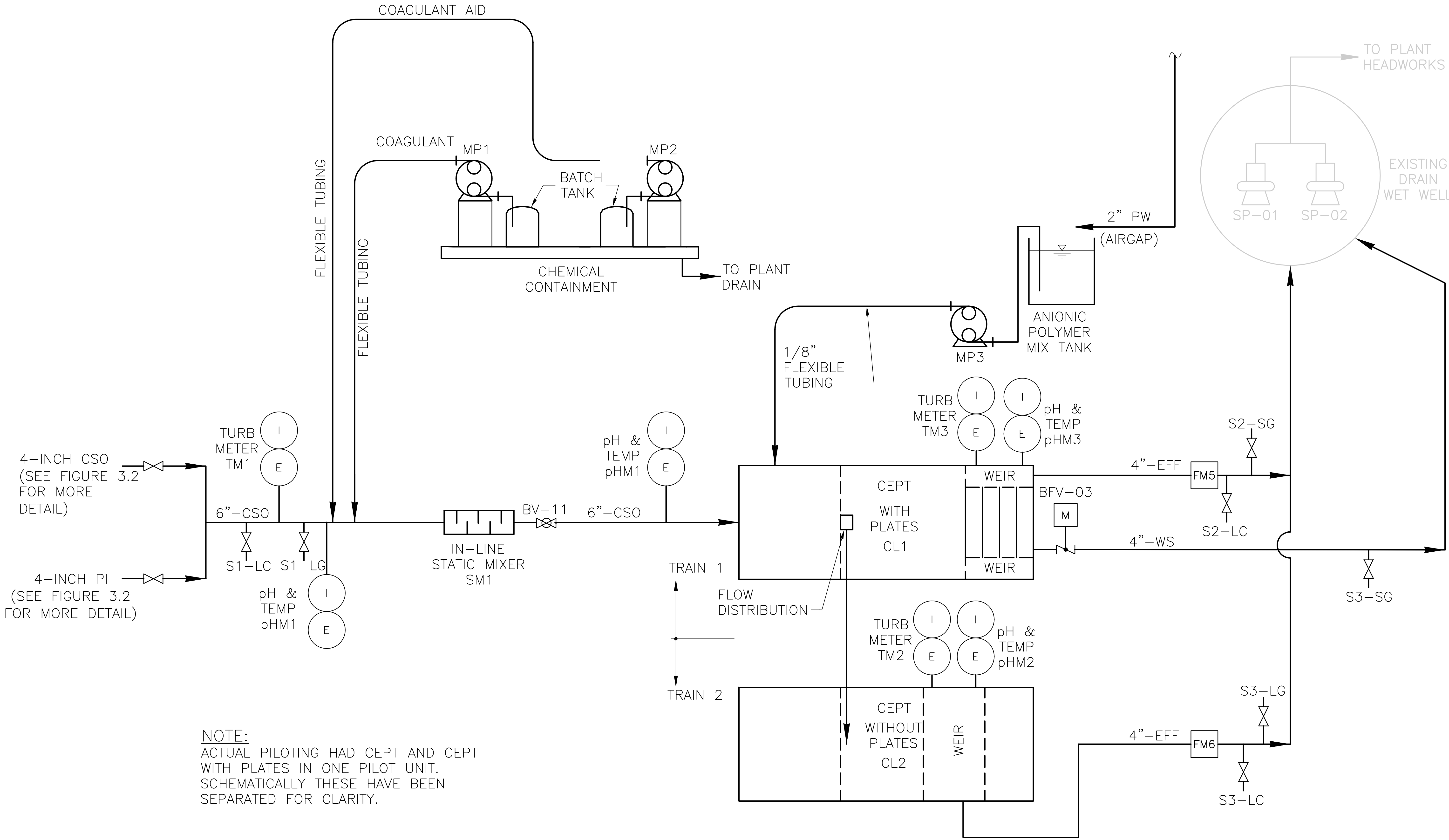
The secondary means of flow control was provided by an adjustable weir in the CEPT sedimentation zone of the pilot unit. The adjustable weir was 2-feet in width and depending on its position enabled operators to split flow between the CEPT and CEPT+plates portion. Prior to each piloting trial, a predetermined SOR from the testing sequencing was selected and the adjustable weir was positioned to achieve the requisite flow rate. Weir adjustment was performed manually prior to each piloting run and verified during the course of piloting by comparing the effluent flow meter readings for each section. **Photograph 3.5** shows the adjustable weir in the CEPT sedimentation zone section.

Photograph 3.5 Adjustable Weir in CEPT Sedimentation Zone



3.3 Field Instruments

Field instruments were used to measure flow, turbidity, pH, and temperature. Calibration occurred according to the manufacturer instructions or if a meter was observed to drift. **Figure 3.4** shows a process schematic of the pilot unit with field instrumentation type and location called out. All data recorded during the pilot runs can be found in **Appendix B**.



NOTE:
ACTUAL PILOTING HAD CEPT AND CEPT WITH PLATES IN ONE PILOT UNIT. SCHEMATICALLY THESE HAVE BEEN SEPARATED FOR CLARITY.

P:\19897\67187\rept\ PFD_1 11/05/08 13:24 muglerrm XREFS: 11X17BDR

FIGURE 3.4
PILOTING LAYOUT SCHEMATIC

An instrumentation list has been provided in **Table 3.4** for reference.

Table 3.4 Pilot Instrumentation

Item Designation	Capacity or Size	Description	Signal	Units
FM1	400 gpm	Flow Meter – C3 Line	DATA LOGGER	GPM
FM2	300 gpm	Flow Meter - PI Line	DATA LOGGER	GPM
FM3	300 gpm	Flow Meter - PI Line prior to blending	DATA LOGGER	GPM
FM4	400 gpm	Flow Meter – From Blending to Pilot Unit	DATA LOGGER	GPM
FM5	400 gpm	Flow Meter - CL1 Eff Line (CEPT)	DATA LOGGER	GPM
FM6	400 gpm	Flow Meter - CL2 Eff Line (CEPT+plates)	DATA LOGGER	GPM
TM1	-	Turbidity Meter - PI + C3 Line (blend)	DATA LOGGER	NTU
TM2	-	Turbidity Meter - CL1 Eff Line (CEPT)	DATA LOGGER	NTU
TM3	-	Turbidity Meter - CL2 Eff Line (CEPT+plates))	DATA LOGGER	NTU
PHM1	-	pH and Temp Meter - CSO Line (blend)	DATA LOGGER	pH, °F
PHM2	-	pH and Temp Meter - CL1-Eff Line (CEPT)	DATA LOGGER	pH, °F
PHM3	-	pH and Temp Meter - CL2-Eff Line (CEPT +plates)	DATA LOGGER	pH, °F

3.4 CSO Make-up Facilities (Dilution and Capacity)

Wet Weather flows at West Point are characterized by flows in excess of 300 MGD. At this point, the excess flow (greater than 300 MGD) by-passes secondary treatment process and is blended with the remaining secondary treated flow prior to disinfection.

During the course of piloting a blending system was utilized a majority of the time to create a dilute CSO mixture consisting of PI and C3, which served as a surrogate for CSO events. C3 was chosen as the dilution source over potable water since West Point has limited potable water capacity. A target TSS concentration range was determined based on information from existing CSO outfalls and served as the primary basis of the blend as outlined in **Table 3.5**. Provisions to have the pilot unit run on diluted PI were incorporated into the process piping should a wet weather event occur prior to daily piloting operations.

Table 3.5 Blend Information

Stream or Parameter	Value
Primary Influent (PI) TSS, mg/l	220 to 260
Secondary Effluent (C3) TSS, mg/l	10 to 15
Dilution Ratios	2:1 and 5:1
Pilot Influent TSS Range, mg/l	53 to 102
CSO Historical Data (mean)[a] TSS, mg/l	120
Historical Duwamish CSO (mean) [b] TSS, mg/l	120

[a]Compiled by King County

[b]Compiled from King County Historical CSO data

3.4.1 Dilution Make-up

As mentioned in Section 3.4, the dilution make-up consisted of PI and C3. This dilution was selected as it provided the requisite TSS concentration that could approximate actual CSO sewage overflows, as outlined in **Table 3.5.** The main objective of creating the surrogate was to mimic the typical dilute characteristics of influent in a CSO event. The blending configuration, as shown in **Figure 3.3**, shows the various components that were utilized for this effort.

Originally the test plan had outlined the use of a 10,000 gallon storage tank located inside the multi-use facility. Upon further inspection, it was determined that the piping requirements to utilize this tank would have required significant modifications. Due to the relatively low flow ranges for the piloting operations, the detention time inside the tank would have added another unwanted variable for pilot testing. A substitute 3,000 gallon storage tank was used and located outside adjacent to the pilot unit. The blend tank had a 5 hp submersible Flygt pump (500 gpm capacity) for feeding the pilot and for mixing, which prevented suspended solids from settling. This configuration simplified installation and allowed for a shorter detention time in the blend tank. **Photographs 3.6, 3.7** and **3.8** show the tank and various ancillary components used for the blending operation.

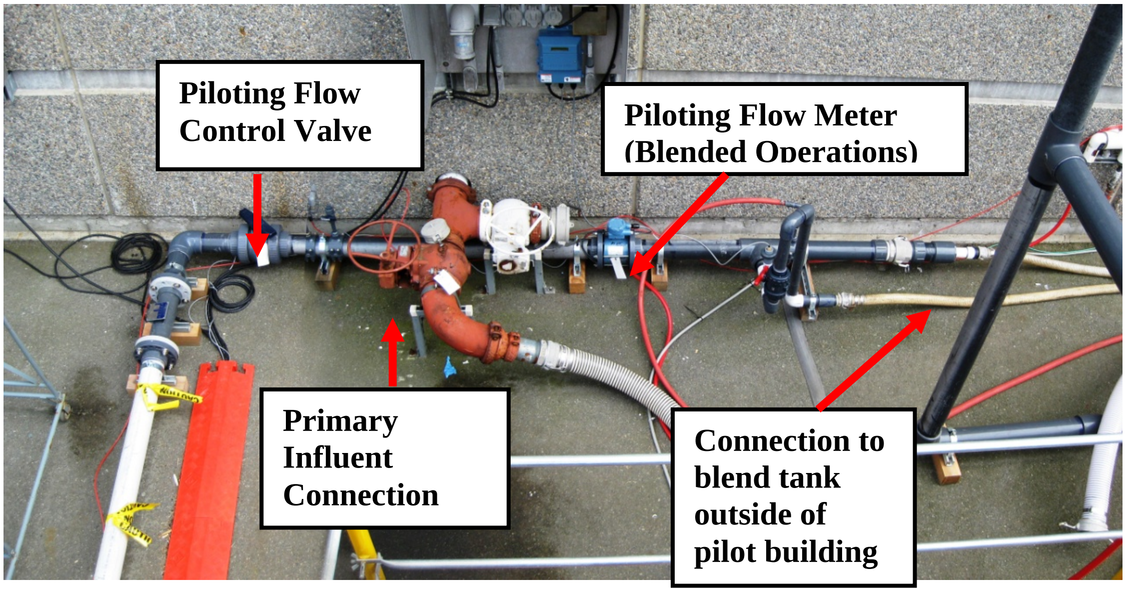
Photograph 3.6 Blend Tank

Photograph 3.7 Blend Tank and Discharge Piping

Photograph 3.8 Blending System - Submersible Pump

The submersible pump was located in the bottom of the blend tank, with its discharge located beneath the water surface. This approach was taken to minimize entrainment of air, which could have impacted the chemical addition downstream in the treatment process. The flow rate to the pilot unit was adjusted by a ball valve downstream of the influent magmeter, as shown in **Photograph 3.9.**

Photograph 3.9 Blending System - Piping Arrangement



Since only a portion of the flow inside the storage tank was being utilized, excess flow was sent to the drain wet-well adjacent to the pilot unit. This allowed for a constant turnover in the blend tank and kept the influent fresh and in suspension. This configuration provided a blend that accurately represented an actual CSO event at a treatment facility. This overflow piping from the storage tank is shown in **Photograph 3.10**.

Photograph 3.10 Blend Overflow System

3.4.2 Capacity

The pilot unit vendor allowed West Point staff to modify and run their equipment as the team saw fit and in accordance with the test plan. Hydraulic tests were performed prior to the data gathering portion of the pilot to verify if the unit was hydraulically effective at the higher flow rates. During the course of testing, the unit was unable to sustain flows greater than 200 gpm through the pilot unit. Upon inspection, the team determined that the baffle openings in the flocculation section, as well as the limited number of openings in the effluent collection system, were creating significant head loss. To address this limitation, a plan was developed to increase the openings in the flocculation section, as well as the modification of the effluent collection system attached to the plate section. For more information on the specifics of the modification of the pilot unit see **Appendix C**.

As a result of the modification to the pilot unit, the safe operating flow was raised from 200 gpm to approximately 300 gpm. Flows slightly higher than 300 gpm were possible; however, the energy imparted by the paddle wheel in the first flocculation section produced some wave interaction with the walls of the pilot unit, resulting in splashing and some spillover.

3.5 Chemical Delivery

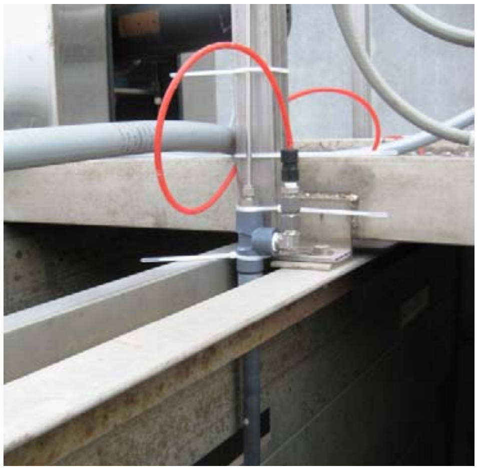
The chemical delivery system incorporated provisions for coagulant, polymer, and alkalinity adjustment via three chemical metering pumps. This equipment was located inside the multi-use facility adjacent to the pilot unit for weather protection and proximity to electrical power and chemical supplies.

Coagulant was injected into the pilot feed downstream of the blend tank. Originally, an in-line static mixer was installed immediately downstream of the coagulant injection point to provide a mixing. However, during the chemical optimization phase, the project team was concerned that the coagulant injection point and static mixer were not imparting the right amount of energy to provide adequate incorporation into the CSO mixture. An evaluation of mixing alternatives was performed with the details included in **Appendix C**. The preferred alternative was the installation of an in-line mechanical mixer in the feed piping to the clarifier. A photo of the in-line mechanical mixer and its location are provided in **Photograph 3.11.**

Photograph 3.11 In-line Mechanical Mixer

During the pilot study, the original configuration for polymer addition was a drip feed directly into the second flocculation tank approximately 3.5 ft from the outer edge of the paddle wheel. However, this setup proved ineffective at forming sizeable floc that readily settled out of the unit. During the chemical optimization phase, a modification was suggested to incorporate an air diffuser similar to an approach taken during the previous CEPT testing at the County's South Wastewater Treatment Plant. The use of compressed air (plant air supply) in conjunction with a polymer drip provided additional mixing energy and allowed for greater particle collision forming more sizable floc. Based on visual observations after this implementation, the air injection method produced floc of greater size and density, which were then carried into the sedimentation zone. **Photograph 3.11A** shows the polymer injection configuration, with **Photograph 3.11B** depicting the configuration in operation. It is important to consider that air injection without sufficient quiescent area to release air may cause settling problems. For the pilot unit, the third flocculation stage served as this quiescent area.

Photograph 3.11A Polymer Injection Configuration



Photograph 3.11B Polymer Injection In Operation

3.5.1 Jar Testing

Jar testing was the first step in the chemical optimization process. Jar testing allowed for rapid measurements of many different samples and solution chemistries in a short period of time. The jar tests narrowed the ranges of optimal chemical dosing values, which hastened the pilot-scale chemical optimization step.

During the Pilot Test Plan development in 2007, jar testing was performed using PI with distilled water as the dilution source. A copy of the 2007 Jar Testing Results can be found in **Appendix D**. The data yielded from these jar tests provided a useful general range of chemical dosages, but it was incomplete by itself. The pilot used a secondary effluent (C3) dilution water that had a different alkalinity than the distilled water used during the jar testing. The difference imparted by the alkalinity of the C3 water was significant enough that new jar tests with C3 water were conducted as part of the pilot to estimate appropriate chemical dosing levels.

For Phase 2, a total of 10 different jar experiments were run with the following chemicals: Zetag 7873 polymer, Nalco IC 34 polymer, MR2405 polymer, PAX 18 coagulant, $FeCl_3$ coagulant, NaOCl, and NaOH for pH adjustment. A breakdown of the dilution criteria can be found in the Method section.

3.5.1.1 Method

A brief description of the testing methodology follows. The sewage influent was taken around 10:30 am on the day of the test and diluted in a 5:1 ratio with makeup water (C3). After addition of each chemical in a given test, the sample was flash mixed for 10 seconds. Flocculation was initiated by mixing at 50 rpm for 4 minutes before polymer addition and at 40 rpm for 4 minutes after polymer addition. The samples were then allowed to settle for 30 minutes. The detailed procedure for the jar testing is attached as **Appendix D**.

3.5.1.2 Results

Table 3.6 shows the variables investigated and the objective of each test.

Table 3.6 Jar Test Results

Test	Coag	Coag Dose (mg/L)	NaOH (mg/L)	NaOCl (mg/L)	Poly	Poly Dose (mg/L)	Objective
1	PAX 18	0-16	0-48	No	Zetag	0.25	Vary PAX18 dose, and test effect of NaOH
2	PAX 18	0-16	No	No	Zetag	0.25	
3	$FeCl_3$	0-70	0-48	No	Zetag	0.25	Vary $FeCl_3$ dose
4	PAX 18	4	12	0-20	Zetag	0.25	Vary NaOCl dose, and test effect of coagulant type
5	$FeCl_3$	50	34	0-20	Zetag	0.25	
6	PAX 18	4	12	No	Nalco	0-1.5	Vary Nalco polymer dose
7	PAX 18	4	12	No	MR2405	0-1.5	Vary MR2405 polymer dose, and test effect of chemicals (PAX18 and NaOH)
8	None	---	No	No	MR2405	0-2	
9	PAX 18	80-130	No	No	Zetag	0.25	Test effect of coagulant (PAX18) overdose

The results of the testing are also provided graphically in **Figures 3.5** through **3.10.**

Figure 3.5 Jar Testing Data – PAX & Zetag

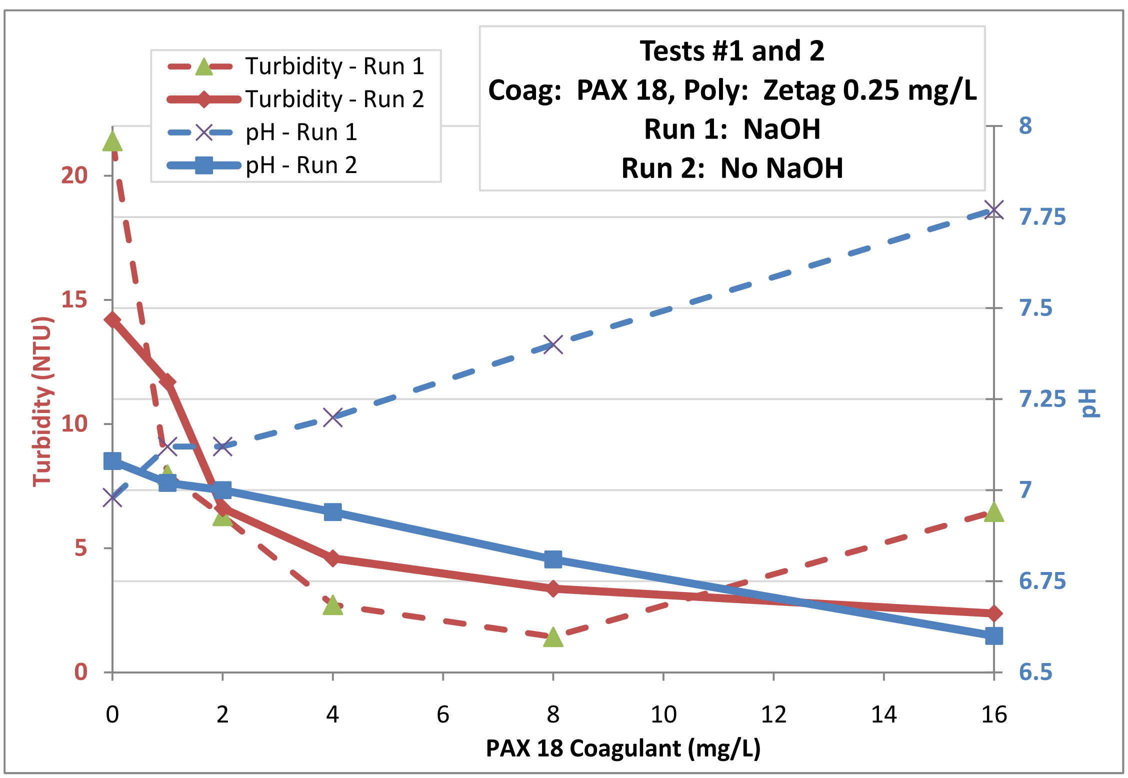


Figure 3.6 Jar Testing Data – $FeCl_3$ & Zetag

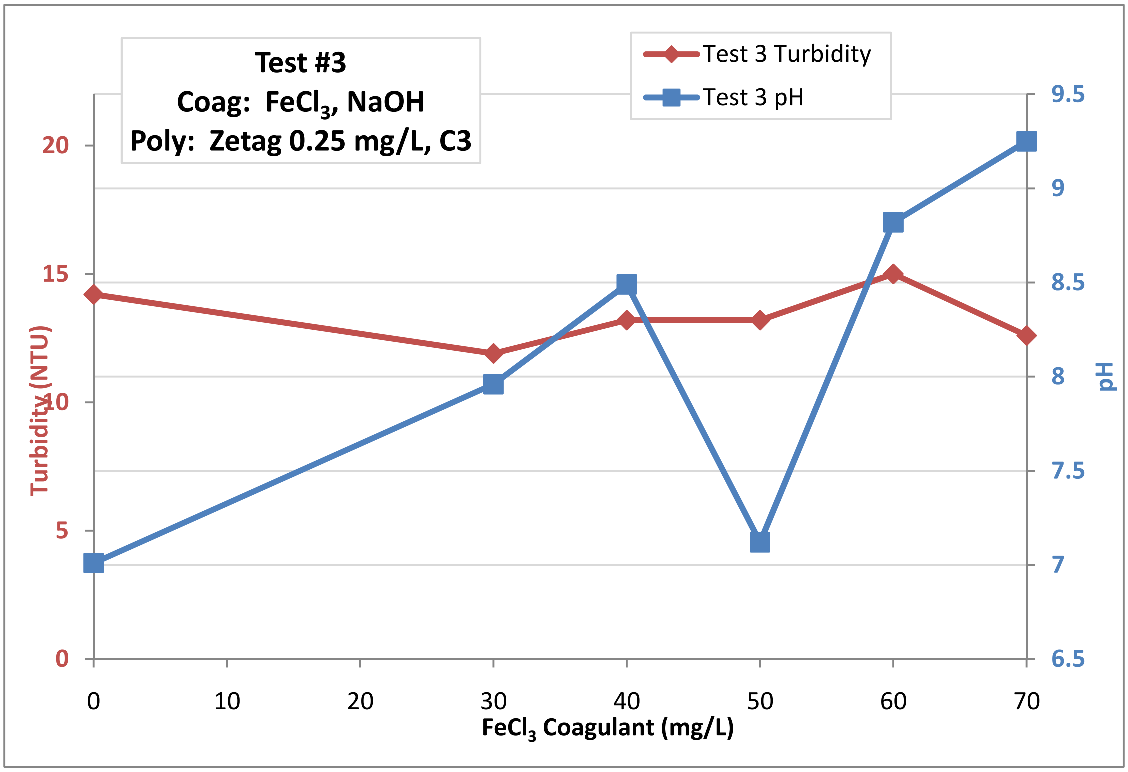


Figure 3.7 Jar Testing Data – PAX vs. $FeCl_3$ with Hypochlorite

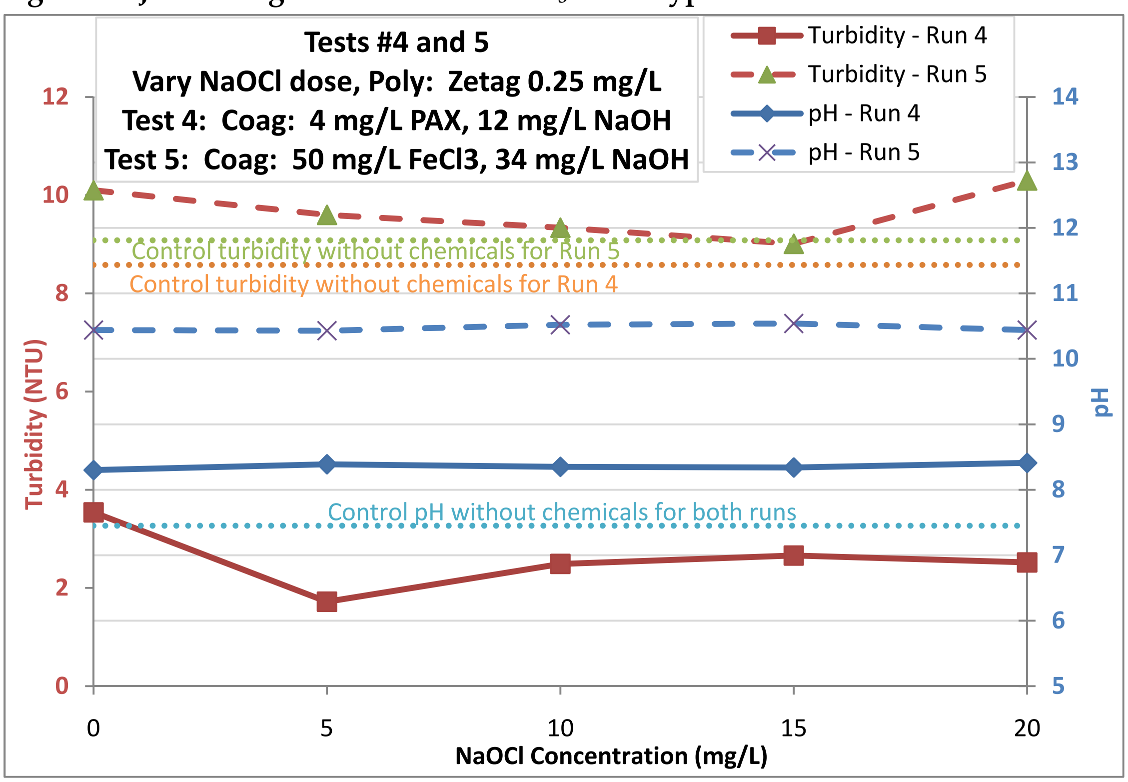


Figure 3.8 Jar Testing Data – PAX & Nalco

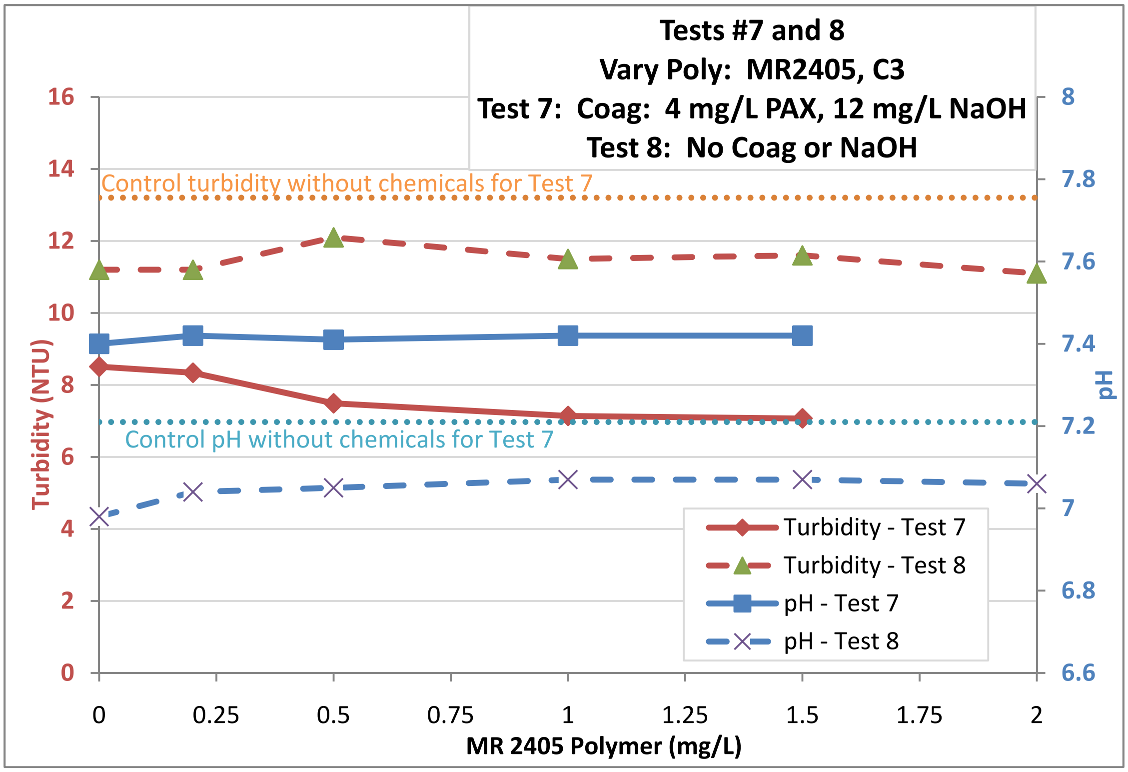


Figure 3.9 Jar Testing Data – MR2405

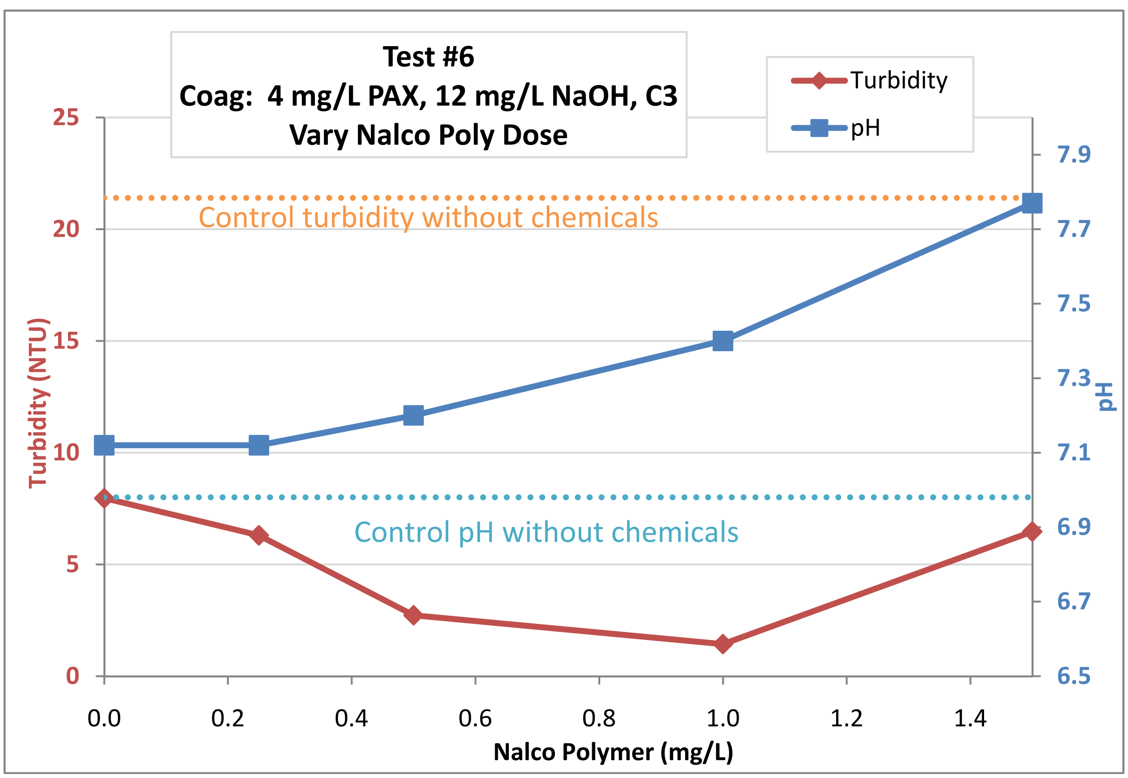
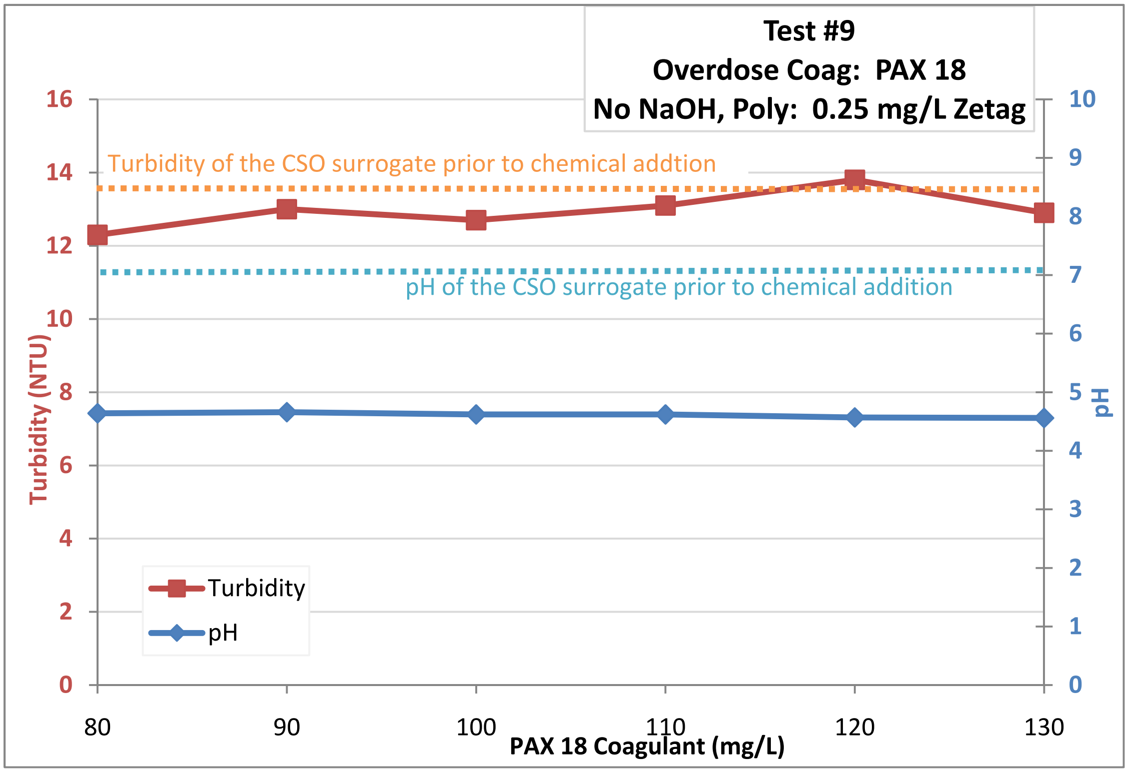


Figure 3.10 Jar Testing Data – PAX Overdose



3.5.1.3 Summary

The jar testing yielded some useful information to take into the chemical optimization phase prior to piloting runs, which has been summarized in **Table 3.7**. All values regarding dosage are with respect to the entire chemical compound (i.e., mg/L of PAX 18, not mg/L of Al). Jar testing represents an ideal testing environment and greater chemical dosing was expected in the chemical optimization stage due to numerous factors. The development of the doses used for performance testing is found in **Section 5.3** Chemical Optimization.

Table 3.7 Jar Testing Summary

Coagulant	Dose
PAX 18	4 mg/L (expressed as Al)
PAX 18 With NaOH Addition	4 to 8 mg/L (expressed as Al)
$FeCl_3$ With NaOH Addition	30 to 40 mg/L

Section 4
Pilot Testing Protocol

As part of the assessment of the CEPT and CEPT + plates technologies, eight primary and eight secondary pilot project objectives were developed. The objectives are listed below:

Primary Objectives

- Evaluate clarification technologies for effectiveness (vs. conventional primary treatment) at removing TSS and COD over a range of surface overflow rates and operating conditions,
- Establish maximum loading rate at which each technology will consistently meet potential discharge requirements,
- Optimize chemical addition and assess sensitivity of technologies to variations in influent characteristics,
- Examine the impact of pre-chlorination on chemical addition and performance through jar testing and, if necessary, field testing,
- Evaluate effluent for suitability for UV disinfection,
- Assess potential for automatic control of chemical addition,
- Identify potential operation and maintenance issues,
- Monitor influent and effluent for established list of conventional, metals and organics parameters.

Secondary Objectives

- Provide information that will help develop a start-up strategy for full-scale CSO treatment facilities,
- Provide qualitative information on the need for fine screening for the selected alternatives and degree of grit removal,
- Characterize the sludge thickening/storage characteristics,
- Determine the cleanup needs and characterize the susceptibility to plugging and fouling,
- Determine what range of chemical dosing is most effective and the relevant detention time,
- Evaluate the variability of effluent with respect to influent turbidity,
- Identify the percent of metals bound in TSS, and
- Demonstrate the maximum sustainable surface overflow rates (SOR), while meeting greater than 50% removal of TSS.

To address these objectives, a pilot test plan including a testing protocol was developed. The complete pilot test plan is included in **Appendix A**. The testing protocol outlined ten different test configurations designed to provide the requisite information and data to resolve the eight primary and eight secondary objectives. Each test was operated multiple runs and was carried out in accordance with the pilot test plan. The tests included the following:

- Dye Testing (Trials 1-8)
- Comparison to West Point Primaries (Trials 9-10)
- Chemical Optimization (Trials 12- 22)
- Capacity Testing (Trial 11)
- Dilution Testing (Trials 12 – 22)
- Loss of Chemical Addition (Trials 26 -27)
- Performance Testing (Trials 45 – 49)
- Hydrograph Testing (Trials 32-43)
- Start-up Testing (Trial 44)
- West Point Storm Events (Trials 50-51)

Setup and configuration information for these test runs are provided below. Results and specific operating conditions of the pilot tests can be found in Section 5. A summary of the test results is included in Section 6.

4.1 Dye Testing

Dye testing trials were run to identify short-circuiting that occurred in the pilot unit, to determine if one zone affected the other, and to confirm the hydraulic retention times inside the pilot unit. For each test run, a concentration versus time plot (tracer curve) was generated to compare with standard plots and with one another, and the mean residence time of the unit was calculated. Based on the shapes of the curves, the team determined the optimal configuration of the baffle in front of the CEPT section, the effect of the CEPT section on the CEPT+plates section, and the effect of the CEPT+plates section on the CEPT section.

The concept of a dye test is straightforward. A known mass and concentration of non-reactive dye is injected into the influent. Continuous measurements of the dye concentration in the effluent are made until all of the dye injected has been measured and accounted for. A graph of the results (concentration over time in the effluent) is plotted on an x-y scale and compared with theoretical concentration versus time curves to characterize the flow.

The two most common dye test approaches are either as step feed (exponential curve function) or plug flow (slug dosing). For the pilot testing, the plug flow slug dose input method was chosen because of the difficulty in performing a step feed test. Step feed tests require a constant dye feed to the pilot unit over an extended period. The primary downside of the plug flow slug dose method is that it requires higher sampling intervals than the step feed to ensure that the peak is captured. A number of different dyes were evaluated for their use in the test including fluoride, Rhodamine WT, and Lithium. Ultimately Rhodamine WT was selected due to its ability to be measured with a portable lab fluorometer. All dye testing was performed in accordance with AWWA Tracer Protocol guidelines.

The dye test was carried out using PI only since Rhodamine can react with chlorine and other oxidants. C3 at West Point has a slight chlorine residual that might have impacted the test results.

Steps taken for Dye Testing:

1. Pilot unit filled with reclaimed water (C2).
2. Pilot unit fed with PI at steady state flow rates to both CEPT and CEPT+plates zones.
3. Pilot unit operated for 30 min or more prior to dye injection
4. Injection of Rhodamine WT dye at the clarifier inlet for a period of 30 seconds.
5. Effluent concentrations from the CEPT and CEPT+plates zones were measured.
6. Total mass of recovered dye was calculated.

Multiple dye tests were performed to find the best operating conditions for the pilot unit and to account for the planned operations of the unit. Tests were performed with and without the adjustable baffle in the front of the CEPT section to determine the optimal configuration to avoid short-circuiting. Tests were performed at two different flow rates to confirm the hydraulics of the unit, and tests were performed with the two zones operated independently and simultaneously to determine if either zone influenced the other during operation. The specifics of flow and other test conditions, including a schematic of the dye injection point, can be found in **Appendix E**.

4.2 Comparison to West Point Primaries

One of the primary objectives in this pilot study was to evaluate the performance of plate clarifiers compared to conventional primary clarifiers. Comparison was a two step process. First, it was confirmed that the primary portion of the pilot unit performed comparatively to the existing West Point clarifiers in terms of typical effluent parameters (TSS and COD removal) when operated on primary influent at the same loading rate. For this test, the pilot unit was operated at 1,400 gpd/ft^2. This step verified that the pilot unit configuration was acceptable and suitable for comparison. During the second step of the comparison process, the CEPT+plates section was operated without coagulants at with an SOR 6 times the West Point overflow rate on a gross surface area basis. The SOR on a projected plate area basis was equivalent to the West Point overflow rate. The data generated by these test runs were compared to historical West Point operations data to determine if pilot unit was comparable to the West Point primaries.

A table comparing the surface overflow rates is provided in **Table 4.1.**

Table 4.1 SOR for Comparison Testing

Facility	SOR, gpd/ft^2
West Point East Primary	800 to 1,000
CSO Pilot CEPT	1,400
CSO Pilot CEPT+plates Gross Surface Area	6,300
CSO Pilot CEPT+plates Projected Plate Surface Area	660

The comparison tests were run on April 8, 2009 and June 17, 2009. During these tests the position of the removable baffle in the front of the CEPT primary zone was different. The April comparison test was conducted with the baffle installed in the upper 2-foot zone approximately 2 feet from the inlet port. The June comparison test was conducted after dye testing and was conducted with the baffle removed. A detailed discussion of the hydraulic and baffle issues is found in **Section 5.1**.

4.3 Chemical Optimization

Chemical optimization was a two step process. Jar tests were performed with the CSO surrogate to determine approximate chemical dosing levels required for optimal TSS and COD removal. Details regarding the jar testing protocol have been provided in Section 3.5.1. Using the jar test data as a baseline, the chemical dosing was fine-tuned on the pilot unit. Optimal performance was determined based on a measurement of the TSS and COD removal in the unit.

During the chemical optimization process, the Nalco 7768 polymer was varied from 0 to 2 mg/L in various trials, and the Zetag 7873 polymer was varied from 0 to 4 mg/L. Tests were run at multiple surface overflow rates and coagulant (PAX 18) dosages. In addition, a trial was run utilizing the GE MetClear 2405 coagulant aid. A final chemical optimization trial was also performed using ferric chloride as the coagulant. A summary list of the trial runs and their configuration is provided in **Table 4.2.**

Table 4.2 Run Conditions for Chemical Optimization Trials

Trial	Influent Blend (C3:PI)	Polymer	Coagulant Dose (mg/L)	Polymer Dose (mg/L)	CEPT SOR (gpd/ft²)	Plate SOR (gpd/ft²)
12	5:1	Nalco	0, 1, 2, 4	0	2,880	28,800
13	5:1	Nalco	0, 1, 2, 4	1	2,160	19,200
13A	PI Only, 2:1	Nalco	2	1	2,160	11,733
13B	C3 Only	Nalco	0, 2, 4	1	2,160	19,200
13C	2:1	Nalco	20	0	2,160	19,200
13D	5:1	Nalco	8, 12, 16, 20	0	2,160	19,200
14	5:1	Nalco	0, 1	1	4,320	28,800
15	5:1	Nalco	0, 1	1	2,160	19,200
16	5:1	Zetag	0, 1, 2, 4	1	2,880	28,800
17	5:1	Zetag	20,30,40, 50**	1	2,520	28,600
19	5:1	Nalco	12	0.5, 1, 1.5, 2	2,160	19,200
20	5:1	Nalco	12*	1.5	2,880	28,800

* PAX 18 was the primary coagulant Metclear MR2405 dosed at 5, 10, 15, 25 mg/L
**Ferric chloride used as coagulant.

4.4 Capacity Testing

Capacity testing was designed to determine the proper range of operation for the CEPT and CEPT+plates sections of the pilot unit, and to determine maximum loading conditions for CEPT and CEPT+plates technologies. Tests were conducted at four different SORs and with two different chemical conditions. One trial used no chemicals (Trial 23), another trial used 12 mg/L PAX as the coagulant and 1.5 mg/L Nalco as the polymer (Trial 24), and a final trial used 40 mg/L of $FeCl_3$ as the coagulant and 1.5 mg/L of Nalco as the polymer (Trial 25). In both of the trials, the surface overflow rates were stepped up sequentially to give a range of removal rates at the various loadings. The four different SORs used for this test are shown in **Table 4.3**. For all tests, the influent was a 2:1 blend of secondary effluent to primary influent.

Table 4.3 Operating Conditions for Capacity Testing

CONDITION	OVERFLOW RATE (gpd/ft²)	
	CEPT	CEPT + Plates
1 – Low	1,900	7,500
2 – Medium	2,700	14,000
3 – Medium-High	4,000	22,000
4 – High	6,000	29,000

4.5 Dilution Testing

To mimic the typical dilute characteristics of the influent water in a wet weather event, the pilot unit was operated on feeds of varying concentrations. A dilution trial was run at SORs of 2,000 and 20,000 gpd/ft^2 for CEPT and CEPT+plates, respectively. Trial 28A was run with 1.5 mg/L PAX while Trial 28A was run with 16 mg/L PAX. To control the TSS concentration of the influent water, the ratio of C3:PI was varied. Both trials were run at C3:PI ratios of 1:1 (most concentrated), 3:1, and 5:1 (most dilute).

4.6 Loss of Chemical Addition Testing

In a real-world scenario, it is possible for many things to go wrong during a storm event. One such possibility is the loss of chemical addition, either via a chemical metering system malfunction or via a facility simply running out of a chemical. To understand how the loss of chemical addition would impact the performance of CEPT and CEPT+plates, two trial runs were configured (Trials 26 & 27). Trial 26 examined the loss of the Nalco Polymer. Trial 27 examined the loss of the PAX coagulant.

For Trial 26 (loss of polymer), the coagulant dosage was held constant at 12 mg/L, and the polymer dose was initiated at 1.5 mg/L. The pilot unit was operated for 75 minutes at surface overflow rates of 2,200 gpd/ft^2 for the CEPT section and 19,000 gpd/ft^2 for the CEPT+plates section (Condition A). The polymer metering pump was shut off, and the pilot operated for 90 minutes with only coagulant (Condition B). After 90 minutes, polymer addition was restored, and the pilot was operated for another 85 minutes (Condition C). TSS and turbidity were monitored to quantify the performance of the CEPT and CEPT+plates technologies.

For Trial 27 (loss of coagulant), the pilot unit was ran with 12 mg/L PAX coagulant and 2 mg/L at the same operating characteristics as the dilution testing (Trial 28). The pilot unit was run for 75 minutes with PAX (Condition A). The PAX coagulant was then shut off for 105 minutes (Condition B), after which the metering pump was turned back on, and the system was run for another 120 minutes (Condition C). TSS and turbidity were monitored to quantify the performance of the CEPT and CEPT+plates technologies.

4.7 Performance Testing

Performance testing was conducted over seven trials. During testing, four different surface overflow loading rates were used, with varying chemical dosing conditions. For trials 32 through 35 the PAX coagulant was dosed at 12 mg/L and the Nalco 7768 was dosed at 1.5 mg/L. For Trials 37 & 38 the $FeCl_3$ coagulant was dosed at 40 mg/L and the Nalco 7768 was dosed at 1.5 mg/L. For Trial 41, the PAX 18 coagulant was supplemented with 15 mg/L of the MetClear product. **Table 4.4** has been populated with the operating conditions for the performance testing.

Table 4.4 Operating Conditions for Performance Testing (Trials 32 - 38 & 41)

Trial Number (PAX)	Trial Number ($FeCl_3$)	Trial Number (PAX with MetClear)	SOR CONDITION	SOR (gpd/ft^2)	
				CEPT+plates	CEPT
32	--	---	A – Low	7,500	2,200
33	--	__	B – Medium	23,000	6,800
34	--	---	C – Medium-High	31,000	9,100
35	--	---	D – High	43,000	13,000
	37	---	B – Medium	23,000	5,800
	38	---	C – Medium-High	32,000	7,200
		41	B - Medium	23,000	6,800

Note: Trial #36 was not performed

In addition to the conventional water quality testing parameters of TSS, VSS, COD and turbidity removal, for these seven trials, the total and soluble metals, PCB's, and trace organics were analyzed in the influent and effluent of both process streams by the King County Environmental Laboratory. The full data from the plant and King County Environmental Laboratory can be found in **Appendix B**. For all performance tests, the sample times were flow-paced, such that the influent and effluent sampling times were staggered to account for the residence times in the sections.

4.8 Hydrograph Testing

To simulate operations during an actual event, the project team developed two dynamic flow conditions to feed to the pilot unit, called hydrograph tests. The tests were designed to see how the two technologies, CEPT and CEPT+plates, would perform under a condition in which the loading rates and storm water strength were changing. CSO storm events are characterized by a period of increasing flows in the interceptors until an overflow begins, cresting with a low-strength, high-flow condition at the peak of the storm, followed by flows tapering off at the end of the event and the tail of the storm remaining in the interceptor.

During the development of the Test Plan, the team analyzed numerous storm events recorded by King County on several CSO outfall locations. A hypothetical storm event was created for the King Street CSO with a return frequency of four times a year. The base flow for the hydrograph was three times the normal flow – the point when the interceptor was assumed to be full. **Figure 4.1** outlines the time event, dilution factor, and flow rates of both PI and C3 used to create the surrogate CSO feed source. The figure also identifies the corresponding influent TSS values prior to the flow entering into the piloting unit. Both flow rate and dilution were variables for the Hydrograph testing. **Figure 4.2** illustrates a hypothetical storm event but with return frequency of twice per year or peak event.

Figure 4.1 Storm/Test Hydrograph - Initial Event

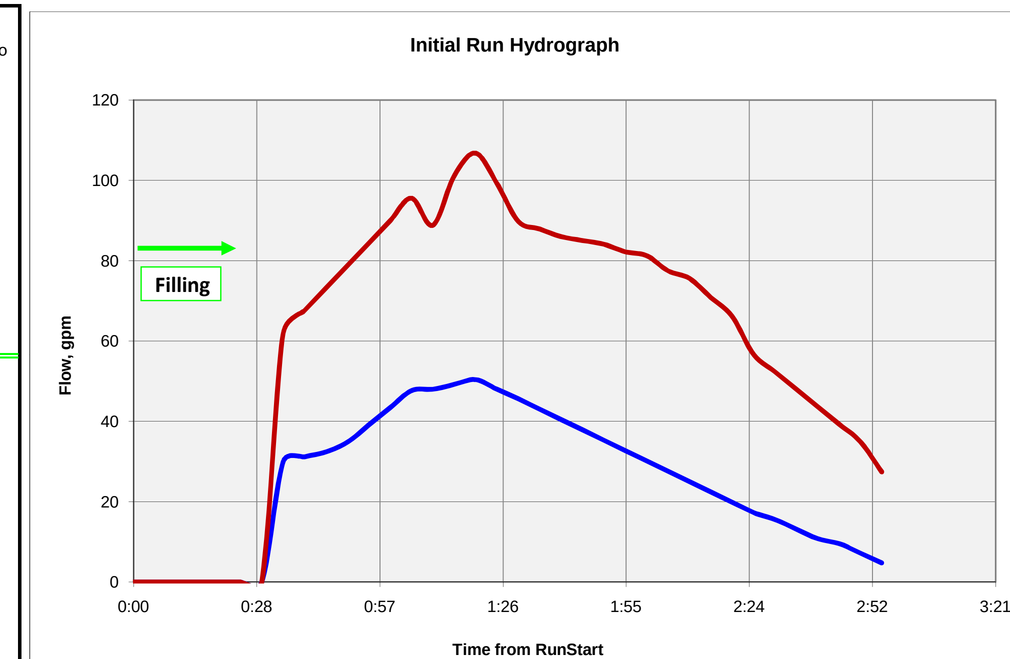
	CEPT - Initial								CEPT with Plates - Initial												
	Hour	Interval	Test Nominal SOR, gpm/sf	gpd/sf	Blend Ratio PI/C3 Blend to achieve desired [TSS]	Feed gpm	TSS mg/l	Discharge gpm	Hour	Interval	Test Nominal SOR, gpm/sf	gpd/sf	Blend Ratio PI/C3 Blend to achieve desired [TSS]	Feed gpm	TSS mg/l	Discharge gpm		Feed to Floc gpm	PI Flow gpm	C3 Flow gpm	Total to Drain gpm
A	12:00 AM	0:05	0.1	173	0.5	1	100	0	12:00 AM	0:05	2.8	4,032	0.5	19	100	0		20	10	10	0
	0:05	0:05	0.4	518	0.5	4	100	0	0:05	0:05	4.2	6,048	0.5	28	100	0		32	16	16	0
	0:10	0:05	0.8	1,136	0.5	8	100	0	0:10	0:05	5.0	7,243	0.5	34	100	0		42	21	21	0
	0:15	0:05	1.2	1,753	0.5	12	100	0	0:15	0:05	5.9	8,438	0.5	40	100	0		52	26	26	0
	0:20	0:05	1.4	2,074	0.5	14	100	0	0:20	0:05	6.7	9,634	0.5	45	100	0		60	30	30	0
	0:25	0:05	1.9	2,691	0.5	19	100	0	0:25	0:05	7.5	10,829	0.5	51	100	0		69	35	35	0
B	0:30	0:05	2.3	3,308	0.5	23	100	0	0:30	0:05	8.4	12,024	0.5	56	100	0	2.1	79	40	40	0
	0:35	0:05	3.0	4,320	0.5	30	100	30	0:35	0:05	9.2	13,219	0.5	62	100	62	2.1	92	46	46	92
	0:40	0:05	3.1	4,493	0.5	31	100	31	0:40	0:05	10.0	14,414	0.5	68	100	68	2.2	99	49	49	99
C	0:45	0:05	3.2	4,666	0.5	32	100	32	0:45	0:05	10.8	15,610	0.5	73	100	73	2.3	106	53	53	106
	0:50	0:05	3.5	5,011	0.5	35	100	35	0:50	0:05	11.7	16,805	0.5	79	100	79	2.3	114	57	57	114
	0:55	0:05	3.9	5,628	0.5	39	100	39	0:55	0:05	12.5	18,000	0.5	84	100	84	2.2	123	62	62	123
D	1:00	0:05	4.3	6,245	0.5	43	100	43	1:00	0:05	13.3	19,195	0.5	90	100	90	2.1	133	67	67	133
	1:05	0:05	4.8	6,863	0.5	48	100	48	1:05	0:05	14.2	20,390	0.5	96	100	96	2.0	143	72	72	143
	1:10	0:05	4.8	6,912	0.5	48	100	48	1:10	0:05	13.2	18,950	0.5	89	100	89	1.9	137	68	68	137
E	1:15	0:05	4.9	7,085	0.5	49	100	49	1:15	0:05	15.0	21,571	0.5	101	100	101	2.1	150	75	75	150
	1:20	0:05	5.0	7,258	0.5	50	100	50	1:20	0:05	15.8	22,781	0.5	107	100	107	2.1	157	79	79	157
	1:25	0:05	4.8	6,912	0.5	48	100	48	1:25	0:05	14.7	21,168	0.5	99	100	99	2.1	147	74	74	147
F	1:30	0:05	4.6	6,566	0.5	46	100	46	1:30	0:05	13.3	19,152	0.5	90	100	90	2.0	135	68	68	135
	1:35	0:05	4.3	6,196	0.5	43	100	43	1:35	0:05	13.0	18,749	0.5	88	100	88	2.0	131	65	65	131
	1:40	0:05	4.0	5,826	0.5	40	100	40	1:40	0:05	12.7	18,346	0.5	86	100	86	2.1	126	63	63	126
	1:45	0:05	3.8	5,456	0.5	38	100	38	1:45	0:05	12.6	18,144	0.5	85	100	85	2.2	123	61	61	123
	1:50	0:05	3.5	5,085	0.5	35	100	35	1:50	0:05	12.5	17,942	0.5	84	100	84	2.4	119	60	60	119
	1:55	0:05	3.3	4,715	0.5	33	100	33	1:55	0:05	12.2	17,539	0.5	82	100	82	2.5	115	57	57	115
G	2:00	0:05	3.0	4,345	0.5	30	100	30	2:00	0:05	12.0	17,338	0.5	81	100	81	2.7	111	56	56	111
	2:05	0:05	2.8	3,974	0.5	28	100	28	2:05	0:05	11.5	16,531	0.5	77	100	77	2.8	105	53	53	105
	2:10	0:05	2.5	3,604	0.5	25	100	25	2:10	0:05	11.2	16,128	0.5	76	100	76	3.0	101	50	50	101
	2:15	0:05	2.2	3,234	0.5	22	100	22	2:15	0:05	10.5	15,120	0.5	71	100	71	3.2	93	47	47	93
	2:20	0:05	2.0	2,864	0.5	20	100	20	2:20	0:05	9.8	14,112	0.5	66	100	66	3.3	86	43	43	86
	2:25	0:05	1.7	2,493	0.5	17	100	17	2:25	0:05	8.4	12,096	0.5	57	100	57	3.3	74	37	37	74
I	2:30	0:05	1.6	2,246	0.5	16	100	16	2:30	0:05	7.8	11,169	0.5	52	100	52	3.4	68	34	34	68
	2:35	0:05	1.3	1,901	0.5	13	100	13	2:35	0:05	7.1	10,241	0.5	48	100	48	3.6	61	31	31	61
	2:40	0:05	1.1	1,555	0.5	11	100	11	2:40	0:05	6.5	9,314	0.5	44	100	44	4.0	54	27	27	54
	2:45	0:05	1.0	1,382	0.5	10	100	10	2:45	0:05	5.8	8,387	0.5	39	100	39	4.1	49	24	24	49
	2:50	0:05	0.7	1,037	0.5	7	100	7	2:50	0:05	5.2	7,459	0.5	35	100	35	4.9	42	21	21	42
	2:55	0:05	0.5	691	0.5	5	100	5	2:55	0:05	4.1	5,846	0.5	27	100	27	5.7	32	16	16	32
H	Shutdown																				

Projected Plate Area 92 sf

Nominal Surface Area For Plates: 6.75 sf

Nominal Surface Area Without Plates: 10 sf

Sludge Production
11 lb
44 gal



Grab Samples during run

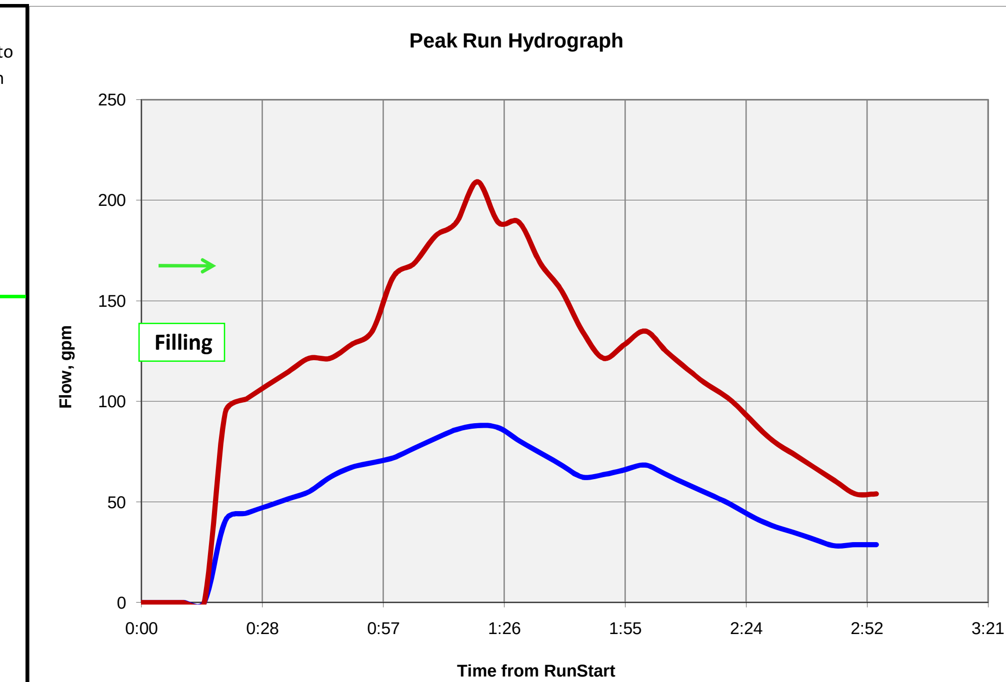
CDM

C:\Documents and Settings\salernomb\My Documents\King County CSO Pilot\from project drive\Revised Figure 4.1 - 10-30-09.xlsx

Figure 4.2 Storm/Test Hydrograph - Peak Event

	CEPT - Peak								CEPT with Plates - Peak											
	Hour	Interval	Test Nominal SOR, gpm/sf	gpd/sf	Blend Ratio PI/C3 Blend to achieve desired [TSS]	Feed gpm	TSS mg/l	Discharge gpm	Hour	Interval	Test Nominal SOR, gpm/sf	gpd/sf	Blend Ratio PI/C3 Blend to achieve desired [TSS]	Feed gpm	TSS mg/l	Discharge gpm		Feed to Floc gpm	Ratio	Total to Drain gpm
A	12:00 AM	0:05	2.4	3,456	0.5	24	100	0	12:00 AM	0:05	10.0	14,400	0.5	68	100	0	2.8	92	0.0	0
	0:05	0:05	3.0	4,320	0.5	30	100	0	0:05	0:05	11.0	15,840	0.5	74	100	0	2.5	104	0.0	0
	0:10	0:05	3.4	4,838	0.5	34	100	0	0:10	0:05	12.0	17,280	0.5	81	100	0	2.4	115	0.0	0
	0:15	0:05	3.7	5,357	0.5	37	100	0	0:15	0:05	13.0	18,720	0.5	88	100	0	2.4	125	0.0	0
	0:20	0:05	4.1	5,875	0.5	41	100	41	0:20	0:05	14.0	20,160	0.5	95	100	95	2.3	135	2.3	135
	0:25	0:05	4.4	6,394	0.5	44	100	44	0:25	0:05	15.0	21,600	0.5	101	100	101	2.3	146	2.3	146
B	0:30	0:05	4.8	6,912	0.5	48	100	48	0:30	0:05	16.0	23,040	0.5	108	100	108	2.3	156	2.3	156
	0:35	0:05	5.2	7,430	0.5	52	100	52	0:35	0:05	17.0	24,480	0.5	115	100	115	2.2	166	2.2	166
	0:40	0:05	5.5	7,949	0.5	55	100	55	0:40	0:05	18.0	25,920	0.5	122	100	122	2.2	177	2.2	177
C	0:45	0:05	6.2	8,986	0.5	62	100	62	0:45	0:05	18.0	25,920	0.5	122	100	122	1.9	184	1.9	184
	0:50	0:05	6.7	9,677	0.5	67	100	67	0:50	0:05	19.0	27,360	0.5	128	100	128	1.9	195	1.9	195
	0:55	0:05	7.0	10,022	0.5	70	100	70	0:55	0:05	20.0	28,800	0.5	135	100	135	1.9	205	1.9	205
D	1:00	0:05	7.2	10,368	0.5	72	100	72	1:00	0:05	24.0	34,560	0.5	162	100	162	2.3	234	2.3	234
	1:05	0:05	7.7	11,059	0.5	77	100	77	1:05	0:05	25.0	36,000	0.5	169	100	169	2.2	246	2.2	246
	1:10	0:05	8.2	11,750	0.5	82	100	82	1:10	0:05	27.0	38,880	0.5	182	100	182	2.2	264	2.2	264
E	1:15	0:05	8.6	12,384	0.5	86	100	86	1:15	0:05	28.0	40,320	0.5	189	100	189	2.2	275	2.2	275
	1:20	0:05	8.8	12,672	0.5	88	100	88	1:20	0:05	31.0	44,640	0.5	209	100	209	2.4	297	2.4	297
	1:25	0:05	8.7	12,528	0.5	87	100	87	1:25	0:05	28.0	40,320	0.5	189	100	189	2.2	276	2.2	276
F	1:30	0:05	8.0	11,578	0.5	80	100	80	1:30	0:05	28.0	40,320	0.5	189	100	189	2.4	269	2.4	269
	1:35	0:05	7.4	10,714	0.5	74	100	74	1:35	0:05	25.0	36,000	0.5	169	100	169	2.3	243	2.3	243
	1:40	0:05	6.8	9,850	0.5	68	100	68	1:40	0:05	23.0	33,120	0.5	155	100	155	2.3	224	2.3	224
	1:45	0:05	6.2	8,986	0.5	62	100	62	1:45	0:05	20.0	28,800	0.5	135	100	135	2.2	197	2.2	197
	1:50	0:05	6.4	9,158	0.5	64	100	64	1:50	0:05	18.0	25,920	0.5	122	100	122	1.9	185	1.9	185
	1:55	0:05	6.6	9,504	0.5	66	100	66	1:55	0:05	19.0	27,360	0.5	128	100	128	1.9	194	1.9	194
G	2:00	0:05	6.8	9,850	0.5	68	100	68	2:00	0:05	20.0	28,800	0.5	135	100	135	2.0	203	2.0	203
	2:05	0:05	6.4	9,158	0.5	64	100	64	2:05	0:05	18.5	26,640	0.5	125	100	125	2.0	188	2.0	188
	2:10	0:05	5.9	8,467	0.5	59	100	59	2:10	0:05	17.2	24,768	0.5	116	100	116	2.0	175	2.0	175
	2:15	0:05	5.4	7,776	0.5	54	100	54	2:15	0:05	16.0	23,040	0.5	108	100	108	2.0	162	2.0	162
	2:20	0:05	4.9	7,085	0.5	49	100	49	2:20	0:05	15.0	21,600	0.5	101	100	101	2.1	150	2.1	150
	2:25	0:05	4.3	6,221	0.5	43	100	43	2:25	0:05	13.5	19,440	0.5	91	100	91	2.1	134	2.1	134
I	2:30	0:05	3.8	5,530	0.5	38	100	38	2:30	0:05	12.0	17,280	0.5	81	100	81	2.1	119	2.1	119
	2:35	0:05	3.5	5,040	0.5	35	100	35	2:35	0:05	11.0	15,840	0.5	74	100	74	2.1	109	2.1	109
	2:40	0:05	3.2	4,550	0.5	32	100	32	2:40	0:05	10.0	14,400	0.5	68	100	68	2.1	99	2.1	99
	2:45	0:05	2.8	4,061	0.5	28	100	28	2:45	0:05	9.0	12,960	0.5	61	100	61	2.2	89	2.2	89
	2:50	0:05	2.9	4,147	0.5	29	100	29	2:50	0:05	8.0	11,520	0.5	54	100	54	1.9	83	1.9	83
	2:55	0:05	2.9	4,147	0.5	29	100	29	2:55	0:05	8.0	11,520	0.5	54	100	54	1.9	83	1.9	83
H	Shutdown																			

Projected Plate Area	**92**	sf	**Sludge Production**	
Nominal Surface Area For Plates:	**6.75**	sf	19	lb
Nominal Surface Area Without Plates:	**10**	sf	76	gal



Grab Samples during run

For all hydrograph tests, the sample times were flow dependent, with the influent and effluent sampling times staggered to account for the residence times in the two pilot units. The hydrograph performance testing consisted of multiple test runs with different combinations of coagulant and polymer at optimum dosages. Sampling methodology for hydrograph Trials 45 through 49 is outlined in **Appendix A.**

4.9 Start-up Testing

Start-up testing was originally identified in the Project Test Plan to identify operational concerns from operating a facility that would be used intermittently. During the pilot testing, it was determined that the start-up considerations for a pilot unit were significantly different from the start-up concerns of a full scale facility and that the investigation would not be performed.

4.10 West Point Storm Events

The Project Test Plan also identified operation of the pilot on an actual West Point storm event, as opposed to the use of a CSO surrogate, as an operational test. This test was not performed as a suitable storm for testing did not occur during the piloting phase of the project.

4.11 Sampling and Testing

Sampling and testing associated with the test runs outlined in this section were carried out in accordance with the sampling protocol and methodology proscribed within the Project Work Plan that is contained in **Appendix A**.

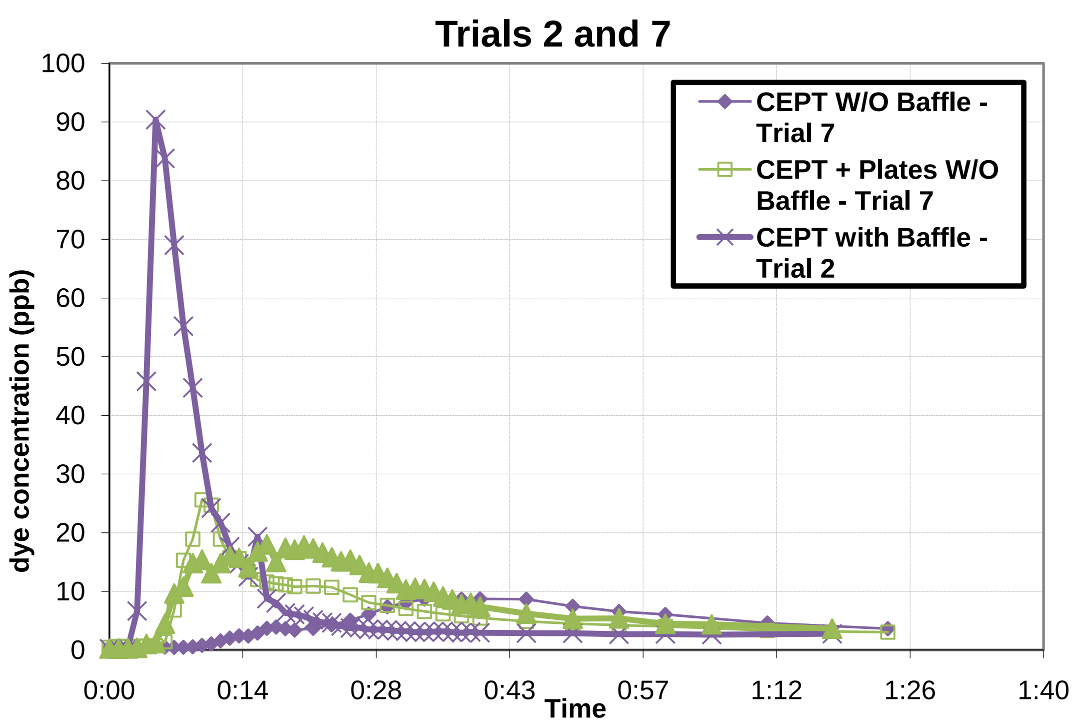
Section 5
Piloting Results

This section summarizes the results of the testing conditions outlined in the Pilot Test Plan and discussed in greater detail in Section 4: Pilot Test Protocol. The results provided here were used to make conclusions and recommendations regarding the CSO technologies in Section 6: Summary and Interpretation of Results. All testing data is contained in **Appendix B.**

5.1 Dye Testing

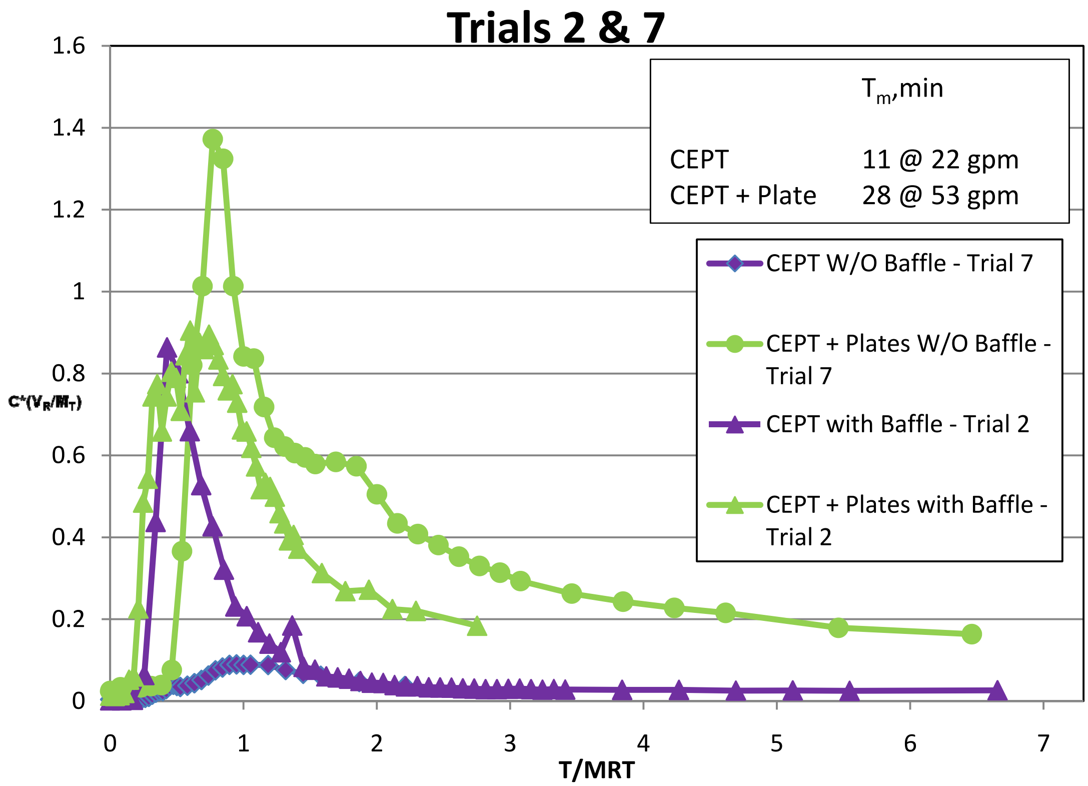
A primary feature of the dye test was to determine if short circuiting was occurring within pilot unit. To test this, two dye tests were conducted in Trials 2 and 7, one with the adjustable baffle in place, one without the adjustable baffle in place. From these tests, a mean residence time within the pilot unit was calculated and compared to the theoretical hydraulic residence time of the unit. In Trial 2, with the removable baffle in place, an early peak was observed before the theoretical hydraulic residence time of the unit had passed. In Trial 7, with the adjustable baffle removed, the early peak was absent, and the mean residence time of the unit more closely matched the theoretical hydraulic residence time. The results of Trials 2 and 7 have been graphed on **Figure 5.1.**

Figure 5.1 Dye Test With and Without the Baffle Installed



A normalized graph of the results of Trials 1 and 4 has been provided in **Figure 5.2.**

Figure 5.2 Dye Test With and Without the Baffle Installed (Normalized)



Based on the results of the dye tests in Trials 2 and 7, it was determined that the baffle contributed to short circuiting and that it would be removed for subsequent trials and investigations.

To determine the effect that one zone had on the other, three dye tests were completed. It was hypothesized that the pilot configuration, with both clarification sections in the same unit, may produce erroneous data due to the two zones not acting independently. Dye tests were run with both sections operating (Trial 7), with just the CEPT section operating (Trial 6), and with just the CEPT+plates section operating (Trial 4). If the curve shapes for a given section matched, whether or not the other section was in operation, it was determined that the sections behaved independently and that the results were valid.

Figure 5.3 shows the results of the testing for Trials 6 and 7. A normalized graph of the data is provided in **Figure 5.4.** When the CEPT section was run by itself, with flow to the CEPT+plates section blocked off, data represented by the green triangles was obtained. When the CEPT section was run in conjunction with the CEPT+plates section, data is represented the magenta diamonds.

Figure 5.3 Dye Test for CEPT With and Without the CEPT+plates Operating

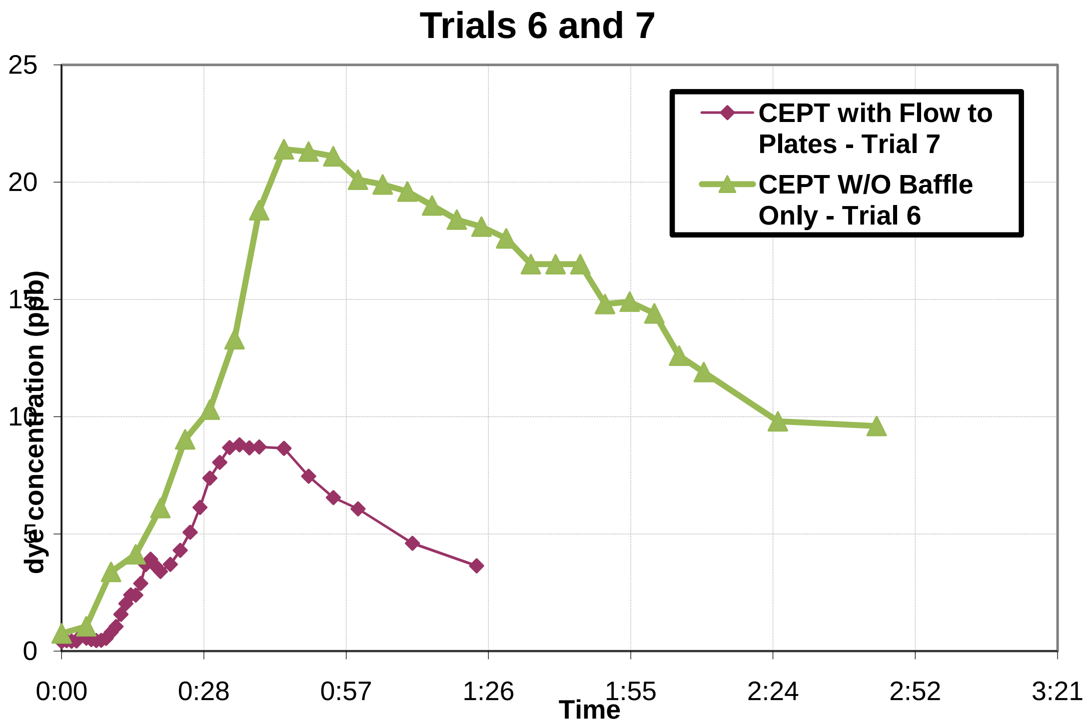
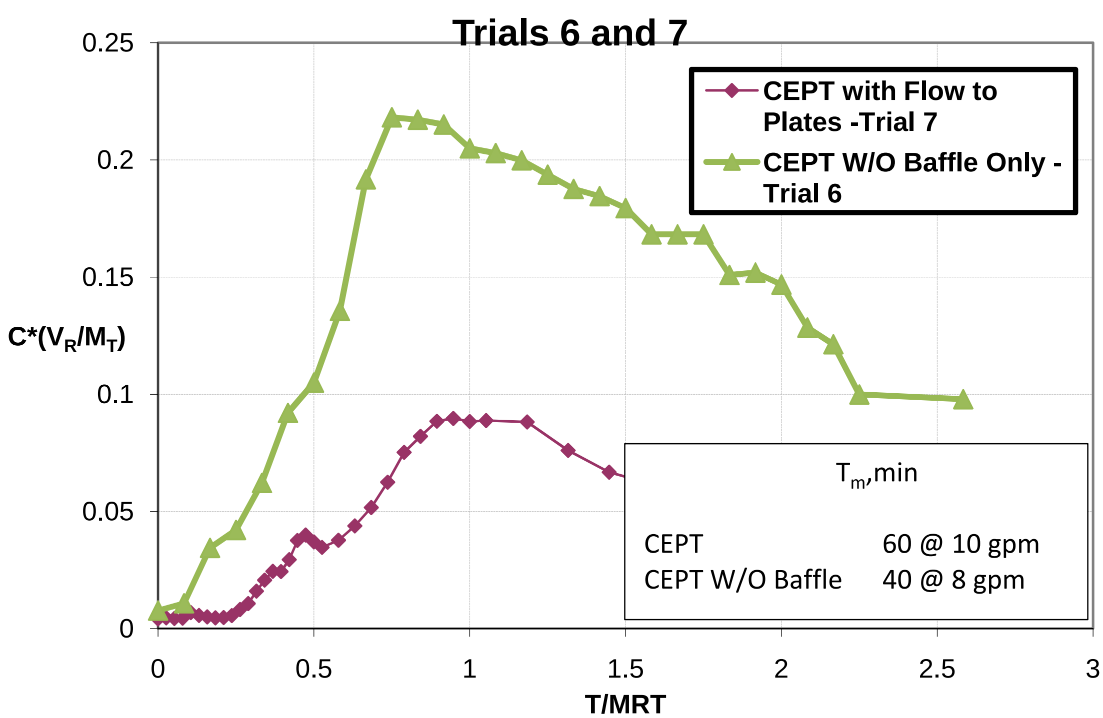


Figure 5.4 Dye Test for CEPT With and Without the CEPT+plates Operating (Normalized)



Although the two curves do not match in magnitude, they are nearly identical in shape, suggesting that the CEPT section is not impacted by the operation of the CEPT+plates zone. The difference magnitude of the two curves is likely the result of two factors. First, the overall flow rate to the pilot unit was reduced during Trial 6, which increased the concentration of the dye being sent to and passed through the CEPT section. Second, with CEPT+plates section in operation (Trial 7), a portion of the dye was diverted through that section and not through the effluent of the CEPT section. The combined effect of these two factors changed the magnitude of the peaks.

While the above analysis indicated that the CEPT section was not impacted by the operation of the CEPT+plates section, a comparison of the results from Trial 4 and 7 was required to know if the opposite was true. The results of the two trials can be seen in Figure 5.4.

Figure 5.5 Dye Test for CEPT+plates With and Without CEPT Operating

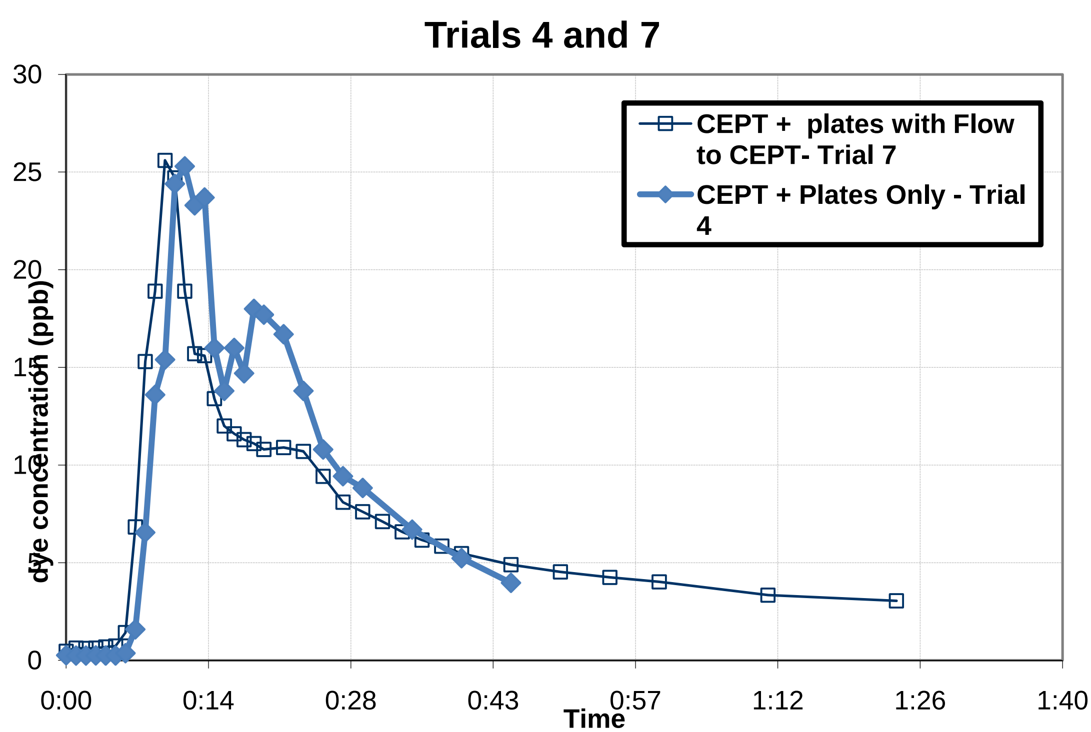


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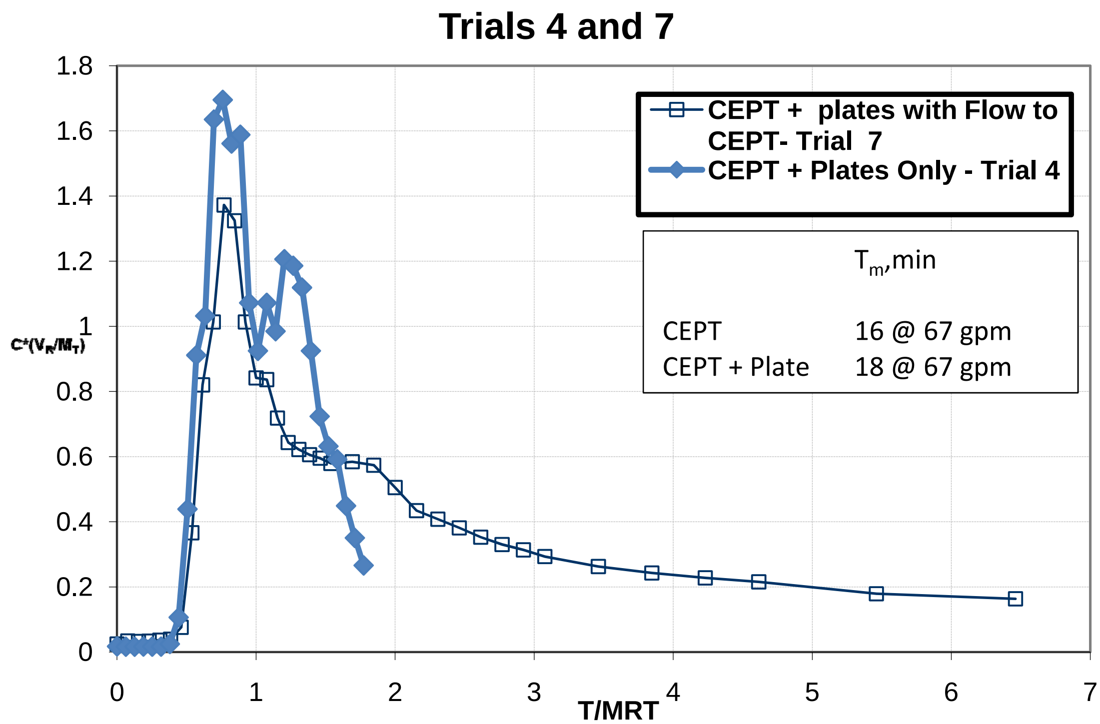
Figure 5.6 Dye Test for CEPT+plates With and Without CEPT Operating (Normalized)



From the results of these dye tests, it was determined that the operation of the CEPT section did not impact the operation of CEPT+plates section and that the two sections could be operated simultaneously for the rest of the project.

Additionally, the results of the dye test provided correlation for the actual mean residence time of the pilot unit and the theoretical hydraulic residence time. Based on this empirical detention time, a lookup table was created for various flows to both sections of the pilot. These table values were used to delay the start of the sampling during performance tests and allowed sampling events to be matched to a particular influent condition and time.

5.2 Comparison to West Point Primaries

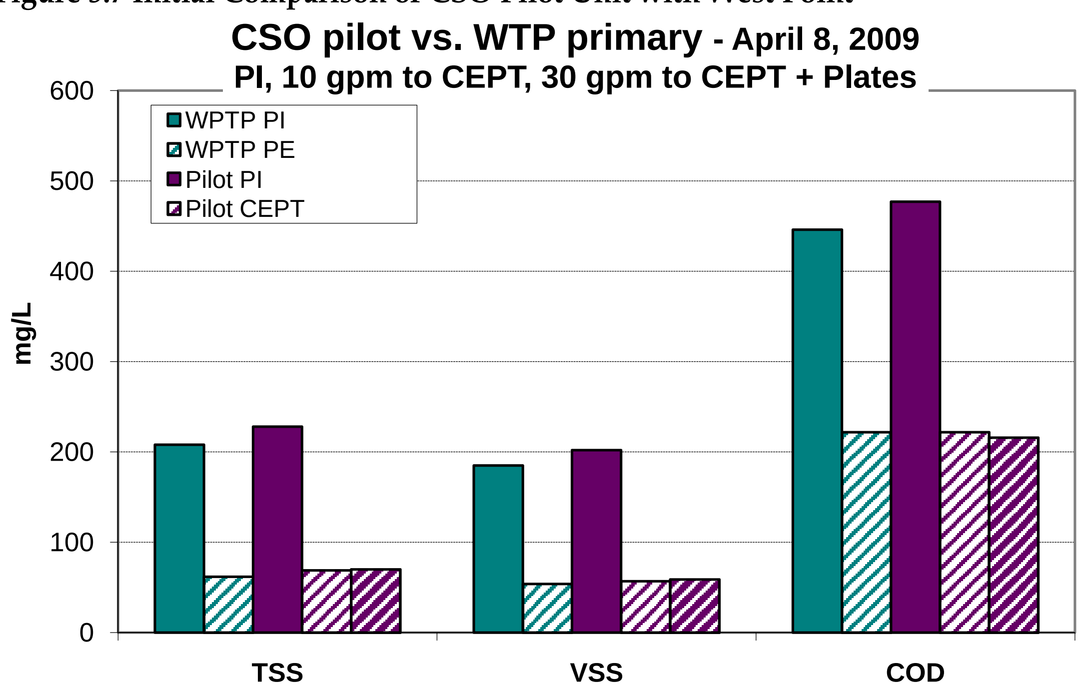
For this test, the pilot unit was operated at conditions that approximated typical loading rates on the West Point Primaries. The testing conditions have been provided in **Table 5.1** for reference.

Table 5.1 Comparison Testing Conditions

Facility	SOR, gpd/ft²	Coagulant, mg/L	Polymer, mg/L	HRT, hrs
West Point East Primary	800 to 1,000	Chemical addition not used as part of West Point Comparison		≈1.9
CSO Pilot CEPT	1,400			≈0.6
CSO Pilot CEPT+plates Gross Surface Area	6,300			≈1.3
CSO Pilot CEPT+plates Projected Plate Surface Area	660			≈1.3

The initial comparison to the West Point primaries was conducted prior to the removal of the baffle in front of the CEPT section. The results of this test are graphed in **Figure 5.7.**

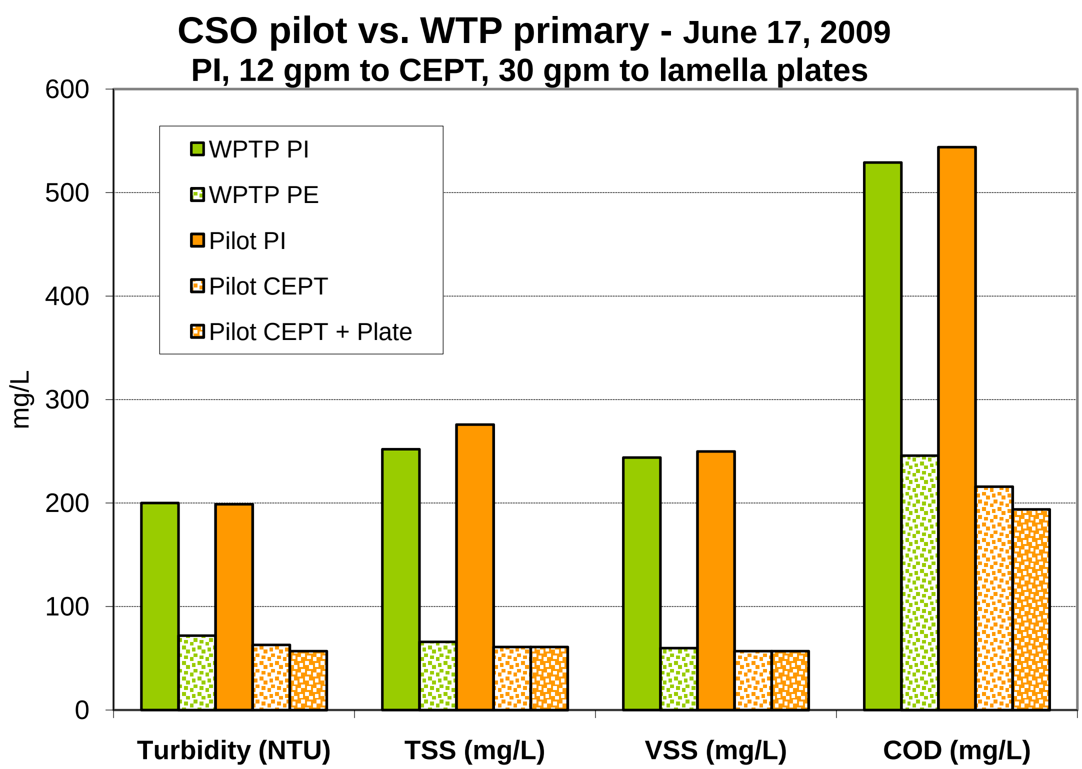
Figure 5.7 Initial Comparison of CSO Pilot Unit with West Point



As seen in **Figure 5.7**, the pilot testing removals approximated actual conditions at West Point. The influent concentrations were within 10% of each other for TSS, VSS and COD. The influent values of 215 mg/L, 190 mg/L, and 450 mg/L for TSS, VSS, and COD, respectively, are typical values experienced by West Point for spring 2009. Likewise, the performance of the CEPT unit approximated the actual performance of the West Point primaries. The effluent concentrations of TSS, VSS and COD for the pilot and the historical West Point data were within 1%, 4% and 1% respectively.

During the timeframe from April 8, 2009 to June 16, 2009, additional dye testing lead to the decision to remove the baffle from the front of the CEPT section. Due this modification, the comparison of the pilot unit to the West Point primaries was repeated. The results of this second test are contained in **Figure 5.8.**

Figure 5.8 Final Comparison of CSO Pilot Unit with West Point



As illustrated in **Figure 5.8**, the removal performance was comparable with the previous testing effort. During this test, the influent values for West Point with regards to TSS, VSS, and COD were in the normal ranges according to West Point operational history. The project team decided to focus on the TSS values since this value is used for the regulatory permit and turbidity values are not. Similar to the comparison test conducted on April 8, 2009, the influent values lie within 10% of each other for both the pilot and the West Point primaries, while the effluent values for TSS, VSS, and COD are within 2%, 6%, and 1% respectively. During this test, the removal rates for the various constituents fall within 5% of each other, and the team concluded that the removal of the baffle had no impact on removal performance at low SORs. **Appendix B** contains the full data from the trials.

5.3 Chemical Optimization

A series of pilot runs were designed to assess the effectiveness of chemical dosing concentrations on removing suspended solids at various CSO strengths and operating conditions. First, twelve trials were run to determine the optimal dosing of coagulants and polymer. Based on experience at South Plant and previous high rate treatment studies at West Point, the two primary coagulants for the study were PAX 18 (Al_2O_3) and ferric chloride ($FeCl_3$). Later trials used a combination of PAX 18 with MetClear (MetClear 2405). The polymers used in the jar test were Nalco 7766 (anionic) and Zetag 7873. Specific specifications for these chemicals are found in **Appendix F**. **Table 5.2** shows the breakdown of variables and operating conditions for the chemical optimization tests**.**

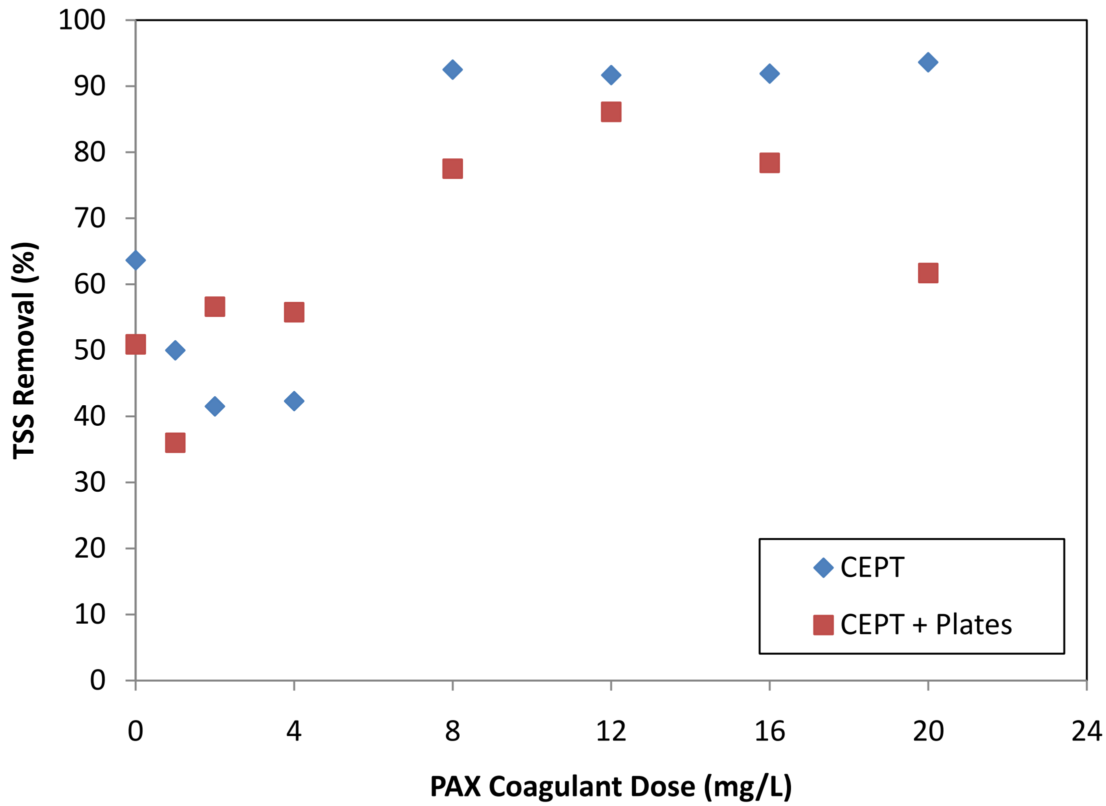
Table 5.2 Run Conditions for Chemical Optimization Trials

Trial	Influent Blend (C3:PI)	Polymer	Coagulant Dose (mg/L)	Polymer Dose (mg/L)	CEPT SOR (gpd/ft^2)	Plate SOR (gpd/ft^2)
12	5:1	Nalco	0, 1, 2, 4	0	2,880	28,800
13	5:1	Nalco	0, 1, 2, 4	1	2,160	19,200
13A	PI Only, 2:1	Nalco	2	1	2,160	11,733
13B	C3 Only	Nalco	0, 2, 4	1	2,160	19,200
13C	2:1	Nalco	20	0	2,160	19,200
13D	5:1	Nalco	8, 12, 16, 20	0	2,160	19,200
14	5:1	Nalco	0, 1	1	4,320	28,800
15	5:1	Nalco	0, 1	1	2,160	19,200
16	5:1	Zetag	0, 1, 2, 4	1	2,880	28,800
17	5:1	Zetag	20,30,40, 50**	1	2,520	28,600
19	5:1	Nalco	12	0.5, 1, 1.5, 2	2,160	19,200
20	5:1	Nalco	12*	1.5	2,880	28,800

* PAX 18 was the primary coagulant Metclear MR2405 dosed at 5, 10, 15, 25 mg/L
**Ferric chloride used as coagulant.

Figure 5.9 shows a summary of the data used to determine the optimal dose of PAX coagulant. This data from trials 13 and 13D were gathered at the same SORs for the respective pilot sections.

Figure 5.9 Summary of Chemical Optimization for PAX Coagulant



Based on the results in **Figure 5.**9, a coagulant dose of 12 mg/L was chosen as the optimal PAX dose. This dose provided the maximum TSS removal, while doses in excess of this negatively impacted removal in the CEPT+plates section, and provided no benefit in the CEPT section. While this dose is significantly higher than the value indicated by the previous jar testing, this was not unexpected. The jar testing used de-ionized water as the dilution source whereas the pilot used higher alkalinity, West Point secondary effluent. The higher alkalinity of the secondary effluent artificially raised the coagulant demand.

The optimum dose for all the coagulants tested is found in **Table 5.3. Appendix B** contains the data from all of the chemical optimization tests.

Table 5.3 Optimum Coagulant Dosages

Coagulant	Dose, mg/L
PAX	12
$FeCl_3$	40
PAX plus Metclear	12 plus 25

It should be noted that the PAX doses are expressed as mg/L of Al, not mg/L of Al_2O_3 as has been reported in some previous pilot testing at West Point.

For subsequent trials and testing, Nalco and PAX were the preferred polymer and coagulant. Jar tests indicated that a dose of 1.0 mg/L of Nalco was effective. However, the Team elected to dose the Nalco 7766 at 1.5 mg/l for all trials to ensure the effectives of the polymer at higher SORs.

PAX was the preferred coagulant because it had proven effective and had minimal impact on pH. Conversely $FeCl_3$ depressed the effluent pH by 0.7 pH units or approximately twice as much as the PAX trials. A lower pH in the treated effluent could make meeting permit requirements for an effluent pH greater than 6.0 difficult to meet and could require the addition of caustic. Additionally, ferric chloride presents storage and handling challenges and is not the pilot team's preferred coagulant for intermittent CSO treatment.

However, it should be noted that two performance trials were completed using a ferric chloride dose of 40 mg/L (Trials 37 and 38). Based on field and laboratory results, the ferric chloride trials removals were significantly better than the PAX at the same SORs as shown in **Table 5.4**.

Table 5.4 Comparison of Ferric Chloride and MetClear trials to PAX

SOR CEPT/CEPT+Plates, gpd/ft^2	Coagulant	Turbidity Removal, %	
6,000 to 7,000 / 23,000 to 28,000		CEPT	CEPT + Plates
	PAX	63	63
	$FeCl_3$	81	76
	PAX + MetClear	81	81
9,000 to 32,000			
	PAX	62	62
	$FeCl_3$	81	81

While the superior performance of ferric chloride was noteworthy, it was not sufficient to displace PAX as the preferred coagulant. The data from these two trials were outliers compared with the rest of the data over the course of study. In the many other trials PAX achieved the same removal rate as the ferric chloride.

MetClear MR2405 is a GE Water product that is reported to enhance metals removal in water treatment. Trial 41 tested the use of MetClear with PAX and used doses of 15 mg/L and 12 mg/L, respectively. The doses achieved high TSS removals along with significant removals of some non-conventional pollutants. As shown in **Table 5.4**, the turbidity removal was similar to other trials. Removal of non-conventional pollutants such as metals is discussed later in this section.

Dilution impacts on coagulant performance were investigated in Trial 28A. Removals remained a constant 90 percent over a dilution range of 1:1 to 5:1. However, the dilution water was secondary effluent and not real surface runoff. The dilution impacts on chemical optimization may still be significant and will need to be monitored in full-scale application.

5.4 Capacity Testing

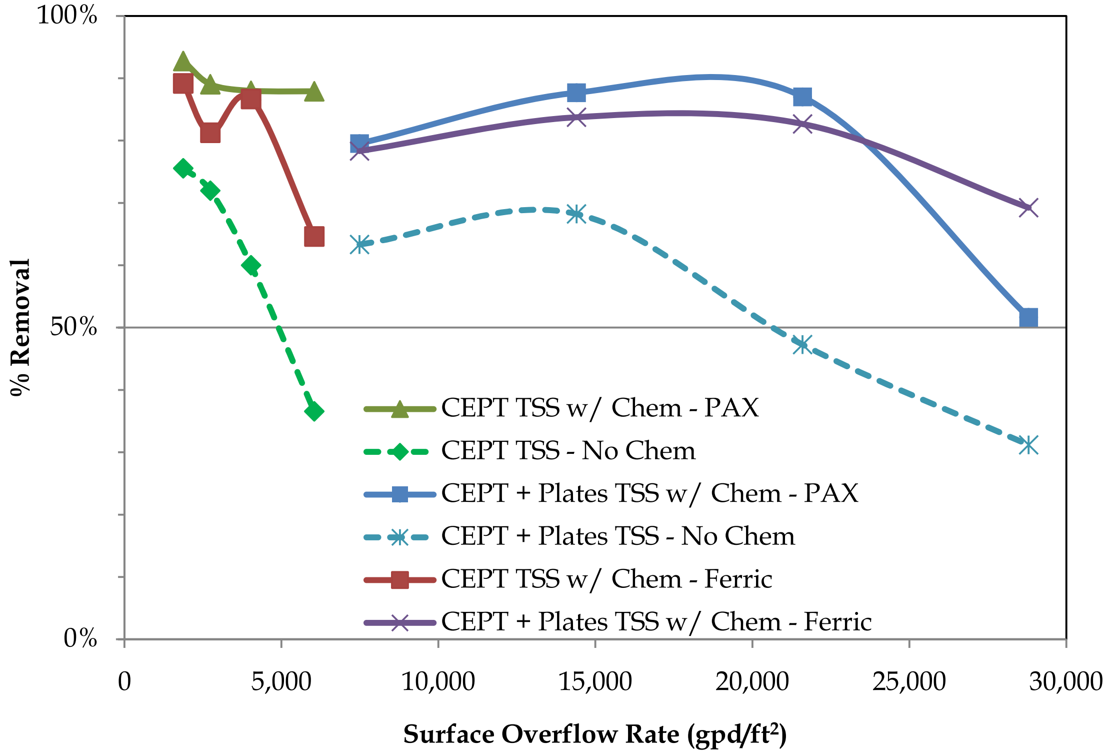
The team performed an initial round of testing in order to determine the proper range of surface overflow rates to investigate in the performance tests and to estimate how surface overflow rate impacted TSS removal. This capacity testing consisted of two tests with different chemical conditions: one with no chemicals (Trial 23), another one with 12 mg/L PAX as the coagulant and 1.5 mg/L Nalco as the polymer (Trial 24), and a final trial used 40 mg/L of $FeCl_3$ as the coagulant and 1.5 mg/L of Nalco as the polymer (Trial 25). In these tests, the surface overflow rates were stepped up sequentially to give a range of removal rates at the various loadings. Four different values were chosen for the conditions, as shown in **Table 5.5**. For both tests, the influent was a 2:1 blend of secondary effluent to primary influent.

Table 5.5 Operating Conditions for Capacity Testing

CONDITION	OVERFLOW RATE (gpd/ft^2)	
	CEPT	CEPT + Plates
1 – Low	1,900	7,500
2 – Medium	2,700	14,000
3 – Medium-High	4,000	22,000
4 – High	6,000	29,000

Figure 5.10 shows the TSS and turbidity percent removal rates for both sections as a function of surface overflow rate.

Figure 5.10 TSS Removals with and without Chemical Addition (PAX + Nalco & $FeCl_3$ + Nalco)



Based on the results graphed in **Figure 5.10,** it was determined that the addition of chemicals had a large impact on the removal rates for both the CEPT and the CEPT+plates sections. Without chemicals, the CEPT+plates section dropped below 50% TSS removal when pushed to approximately 20,000 gpd/ft^2. Likewise, the CEPT section dropped below 50% TSS removal at approximately 5,000 gpd/ft^2. Conversely, with chemicals, neither section failed to remove 50% TSS even at the highest surface overflow rate of 6,000 and 28,000 gpd/ft^2 for CEPT and CEPT + plates respectively. A summary these results are provided in **Table 5.6**.

Table 5.6 Impact of Chemical Addition on Water Quality Parameters

Parameter	**CEPT (SOR = 5,000 gpd/ft²)**		**CEPT + Plates (SOR = 20,000 gpd/ft²)**	
	No Chemicals	PAX plus Nalco	No Chemicals	PAX plus Nalco
TSS Removal, %	50	87	50	90
Ratio	--	1.70	--	1.8

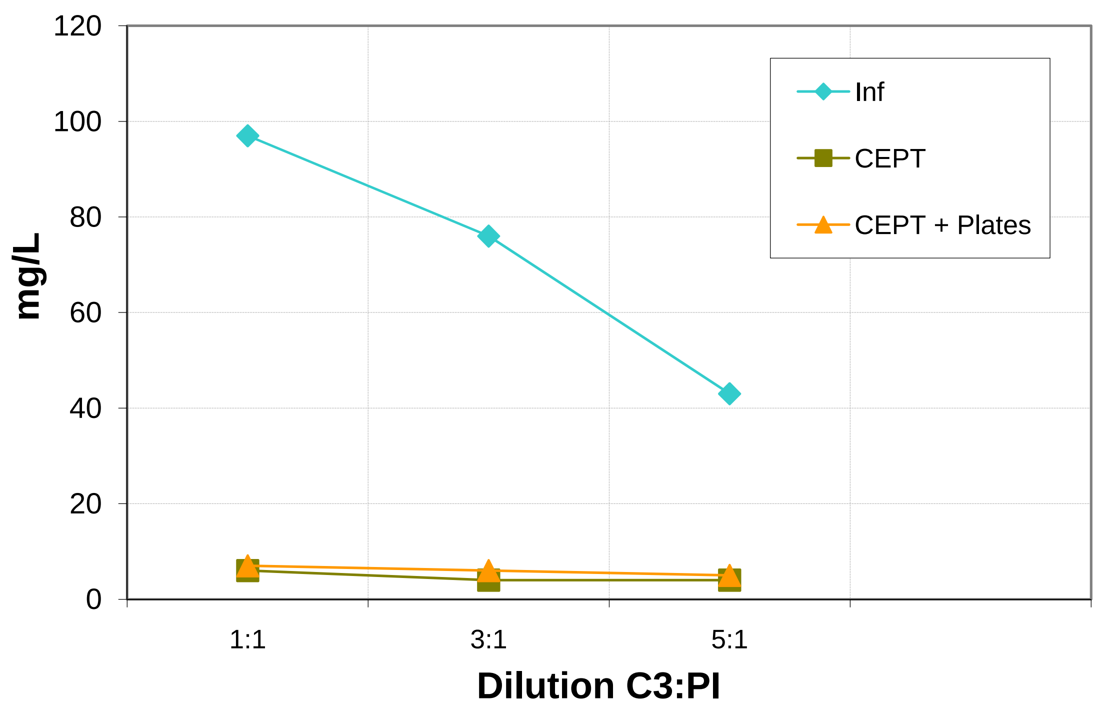
In general, use of a coagulant and polymer resulted in a 70% improvement in removals at the higher SORs. Field sheets, field turbidity and pH data, and laboratory TSS, VSS, COD, alkalinity, and turbidity raw data can be found in **Appendix B**.

5.5 Dilution Testing

Trial 28A was run at 16 mg/L PAX and an SOR of 2,000 and 20,000 gpd/ft^2 for CEPT and CEPT+plates, respectively. To control the TSS concentration of the influent water, the ratio of C3:PI was varied. Both trials were run at three different C3:PI ratios, 1:1 (most concentrated), 3:1, and 5:1 (most dilute).

Figure 5.11 shows the TSS data for Trial 28A, with a high 16 mg/L dose of PAX coagulant.

Figure 5.11 TSS at Various Dilutions



The results of this test, Trial 28A, indicate that performance of the CEPT and CEPT+plates is not greatly influenced by dilution in the ranges investigated when a higher coagulant dose is used. For each dilution, removal efficiency was high and the effluent had low suspended solids concentrations. The data shows the effluent quality remaining constant with varying dilution (see data for Trial 28 in **Appendix B**).

5.6 Loss of Chemical Addition Testing

Loss of chemical addition testing was carried out to determine the impact of losing the polymer and coagulant, and how quickly performance would recover when chemical are restarted.

5.6.1 Loss of Polymer

Both loss of polymer and loss of coagulant runs were carried out at SORs of 2,200 and 19,000 gpd/ft² for CEPT and CEPT+plates, respectively. Chemical dosing was initiated with PAX coagulant dosage of 12 mg/L, and a polymer dose of 1.5 mg/L. The pilot unit was operated in this condition for 75 minutes (Condition A). The polymer metering pump was then shut off, and the pilot operated for 90 minutes with only coagulant (Condition B). After that, polymer addition was restored, and the pilot was operated for another 85 minutes (Condition C).

Figure 5.12 shows the TSS and turbidity measurements for Trial 26. **Table 5.7** summarizes the removal efficiencies for the testing conditions.

Figure 5.12 TSS and Turbidity Measurements for Loss of Polymer. (Trial 26)

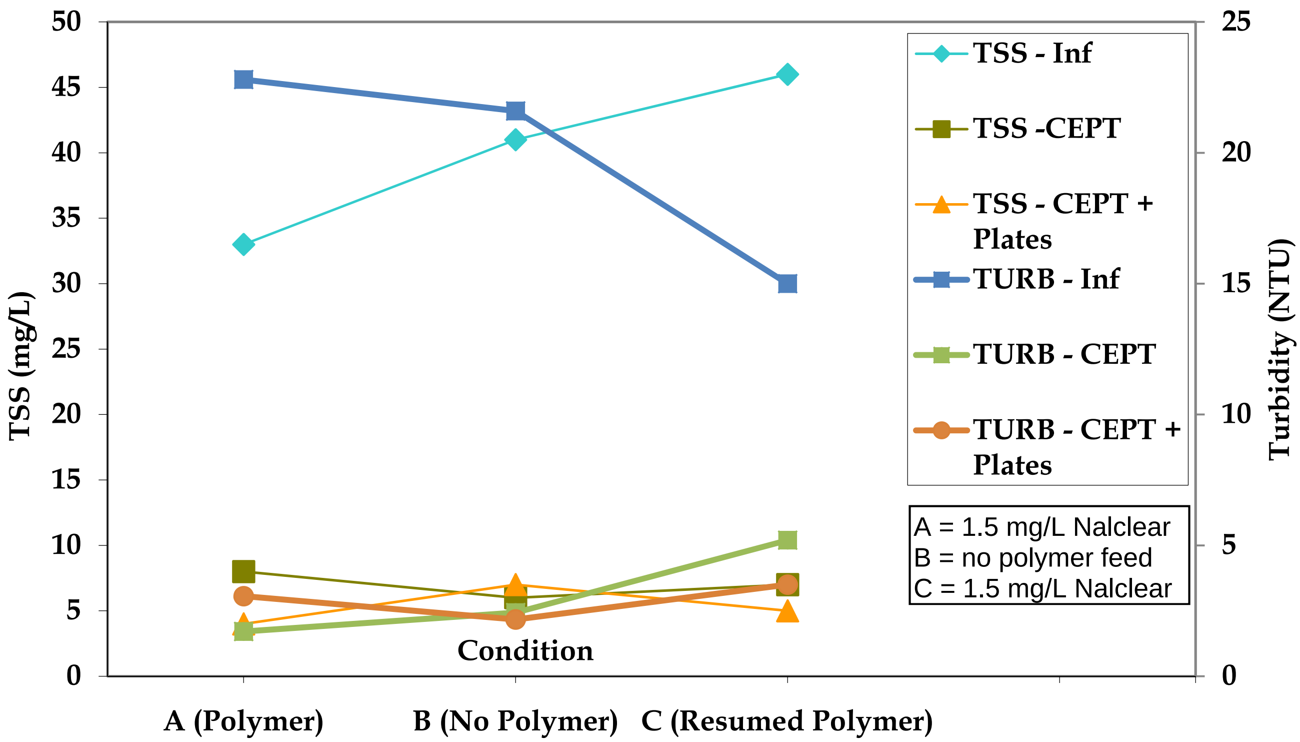
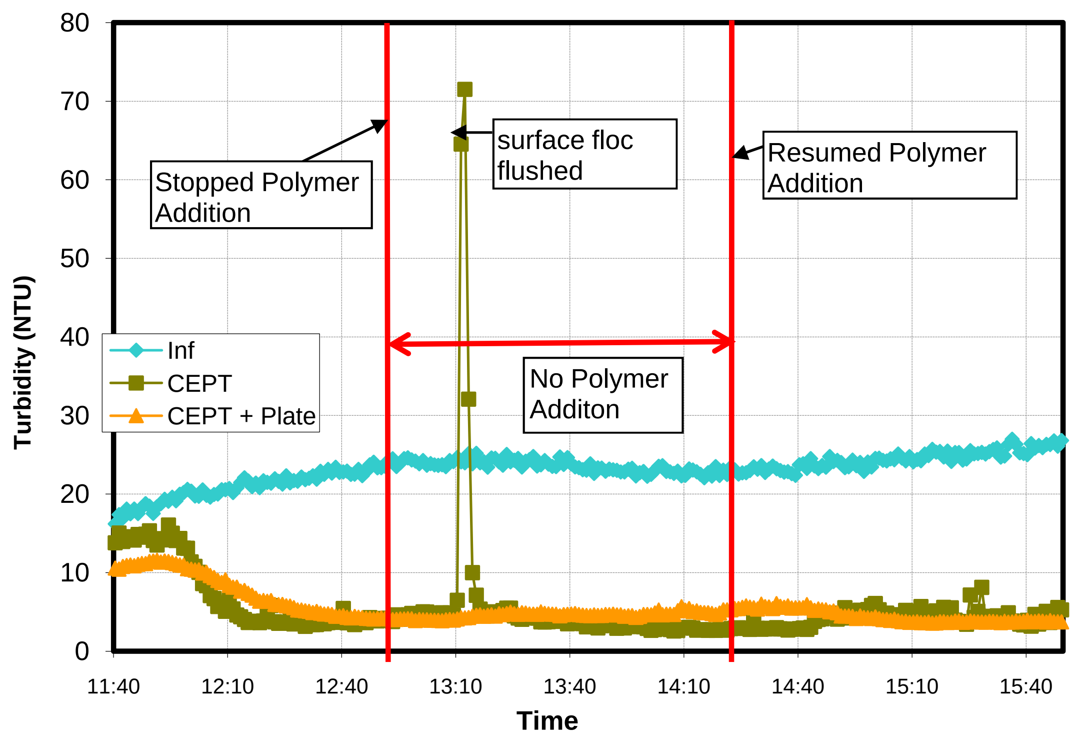


Table 5.7 Removal Efficiencies during the Loss of Polymer Test (Flocculant)

CONDITION	TSS % Removal		Turbidity % Removal	
	CEPT	CEPT + plates	CEPT	CEPT + plates
A – Initial Polymer Feed	76%	88%	93%	87%
B – No Polymer	85%	83%	89%	90%
C – Polymer Restored	85%	89%	65%	77%

Based on these results, it appears that the effluent quality was not significantly affected by the loss or restoration of the polymer addition at low SOR's. This conclusion is substantiated by a continuous graph of turbidity from the field unit. **Figure 5.13** shows the field turbidity measurements from Trial 26. The red vertical lines indicate the times when the polymer addition was shut off and then restored. Shutting off the polymer injection had very limited impact on the effluent quality of the pilot. The full set of data from these trials can be found in **Appendix B**.

Figure 5.13 Field Turbidity Data for Loss of <u>Polymer</u> Test (Trial 26)



5.6.2 Loss of PAX Coagulant

For the coagulant loss test (Trial 27), the pilot unit was ran with 12 mg/L PAX coagulant and 1.5 mg/L of Nalco polymer at the same operating characteristics as the dilution testing (Trial 28). The pilot unit was run for 75 minutes with PAX (Condition A). The PAX coagulant was then shut off for 105 minutes (Condition B), after which the coagulant metering pump was turned back on, and the system was run for another 120 minutes (Condition C). **Figures 5.14** shows the TSS and turbidity values for the pilot influent, the CEPT, and CEPT+plates effluent. It should be noted that approximately 50 minutes after the coagulant was shut off (Condition B), the polymer system ran dry and was not added for the next approximately 100 minutes. Based on the data, and the results of the polymer loss test (Trial 26), this did not appear to influence the trial.

Figure 5.14 TSS and Turbidity Measurements for Loss of Coagulant Test

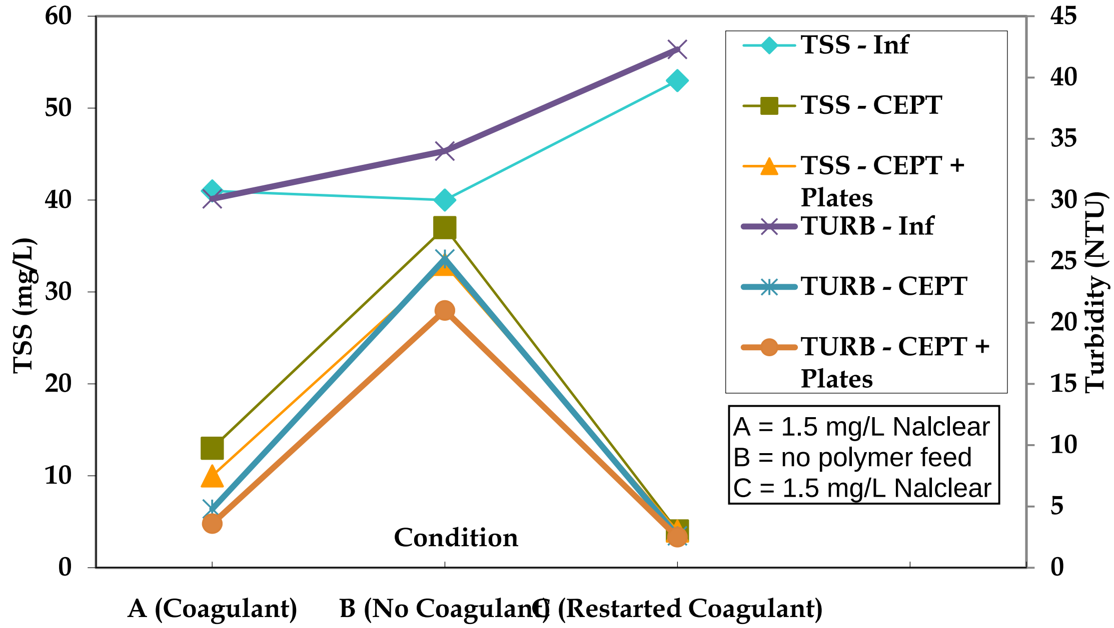


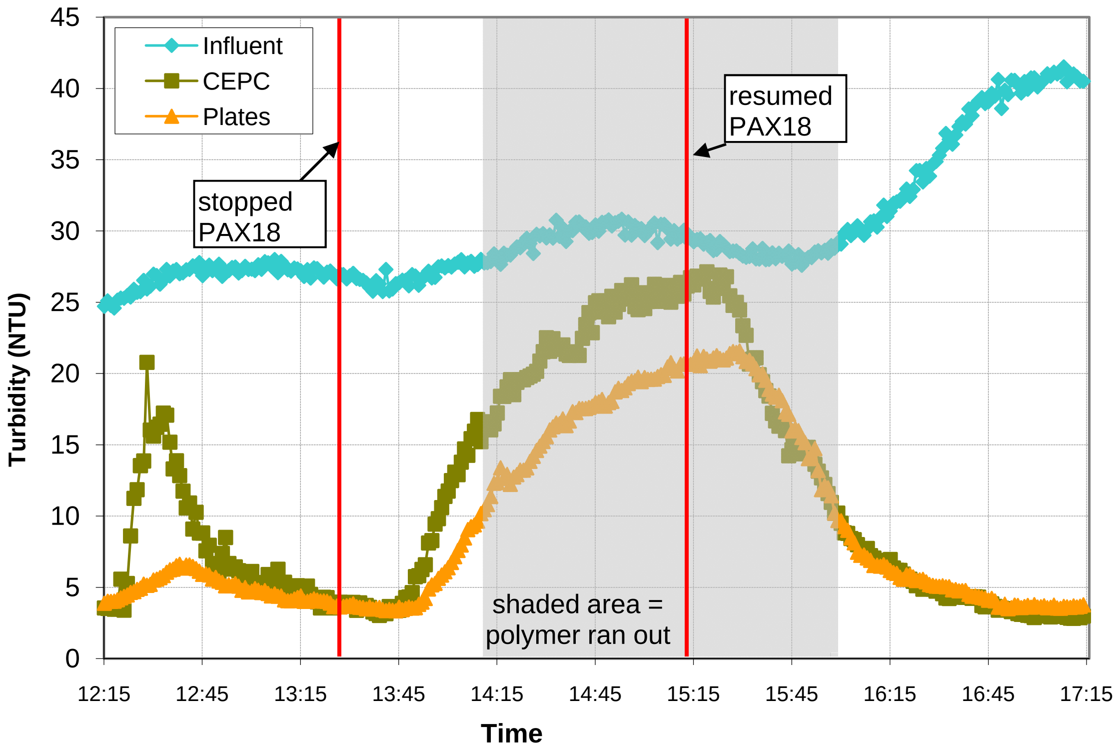
Table 5.8 shows the removal efficiencies for both CEPT and CEPT+plates sections relating to loss of coagulant. Removal efficiency of laboratory TSS dropped considerably in both sections (from 68% to 8% for CEPT, and 76% to 18% for plate) when the coagulant addition was stopped (Condition B). After the coagulant was restarted, TSS removal efficiency recovered up to 92% for both sections in one mean residence time. Although laboratory turbidity removals did not fall as low as TSS removal rates without coagulant, the trend was similar. Field sheets, field turbidity and pH data, and laboratory TSS, VSS, COD, and turbidity raw data can be found in **Appendix B**.

Table 5.8 Removal Efficiencies during the Loss of Coagulant Test (Trial 27)

	TSS % Removal		Turbidity % Removal	
	CEPT	CEPT + plates	CEPT	CEPT + plates
A – Initial Coagulant Feed	68%	76%	84%	88%
B – No Coagulant	8%	18%	26%	38%
C – Coagulant Restored	92%	92%	94%	94%

Figure 5.15 shows the field turbidity measurements from Trial 27. The red vertical lines indicate the times when the coagulant addition was shut off and then restored. The gray shaded area represents the period that the polymer addition stopped. The spike in CEPT turbidity at 12.25 hours was caused by a manual wipe of the turbidity probe.

Figure 5.15 Field turbidity data for Loss of Coagulant Addition Test (Trial 27)



5.7 Performance Testing

The performance tests are steady state trials that form the primary basis for the conclusions drawn from this piloting study. Four different surface overflow loading rates were used, with varying chemical dosing conditions. For these seven trials alone, analyses were run by the King County Environmental Laboratory in order to assess metals removal rates in addition to the standard TSS, VSS, COD, and turbidity removals.

Trials 32 through 35 were performance tests in which 12 mg/L PAX was used as a coagulant and 1.5 mg/L Nalco 7768 was the polymer. For Trial 41, the same conditions were used, except the PAX 18 coagulant was supplemented with 15 mg/L of the MetClear product. **Table 5.9** shows the surface overflow conditions for each performance run. **Figure 5.16** through **5.19** show the removal rates of TSS, turbidity, VSS and COD for each of the testing conditions. The PCB summary data is found in **Table 5.10.**

Table 5.9 Operating Conditions for Performance Testing (Trials 32 - 38 & 41)

Trial Number (PAX)	Trial Number ($FeCl_3$)	Trial Number (PAX with MetClear)	SOR CONDITION	SOR (gpd/ft^2)	
				CEPT + Plates	CEPT
32	--	---	A – Low	7,500	2,200
33	--	___	B – Medium	23,000	6,800
34	--	---	C – Medium-High	31,000	9,100
35	--	---	D – High	43,000	13,000
	37	---	B – Medium	23,000	5,800
	38	---	C – Medium-High	32,000	7,200
		41	B - Medium	23,000	6,800

Note: Trial #36 was not performed.

Figure 5.16 TSS Removal Rates with and without MetClear at Various SORs

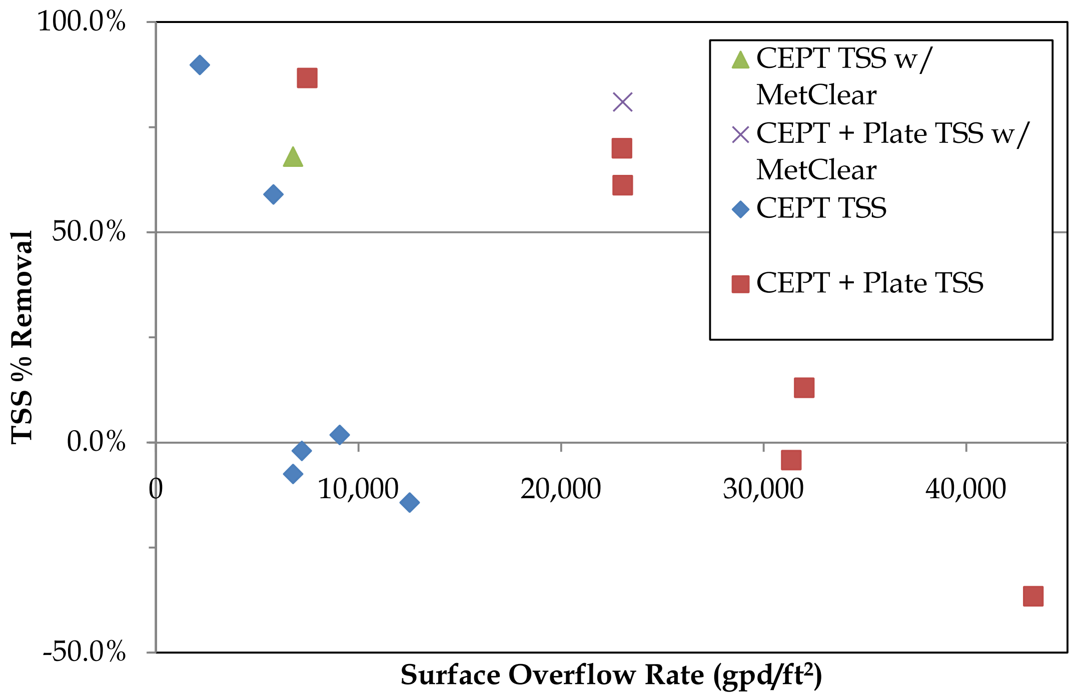


Figure 5.17 Turbidity Removal Rates with and without MetClear at Various SORs

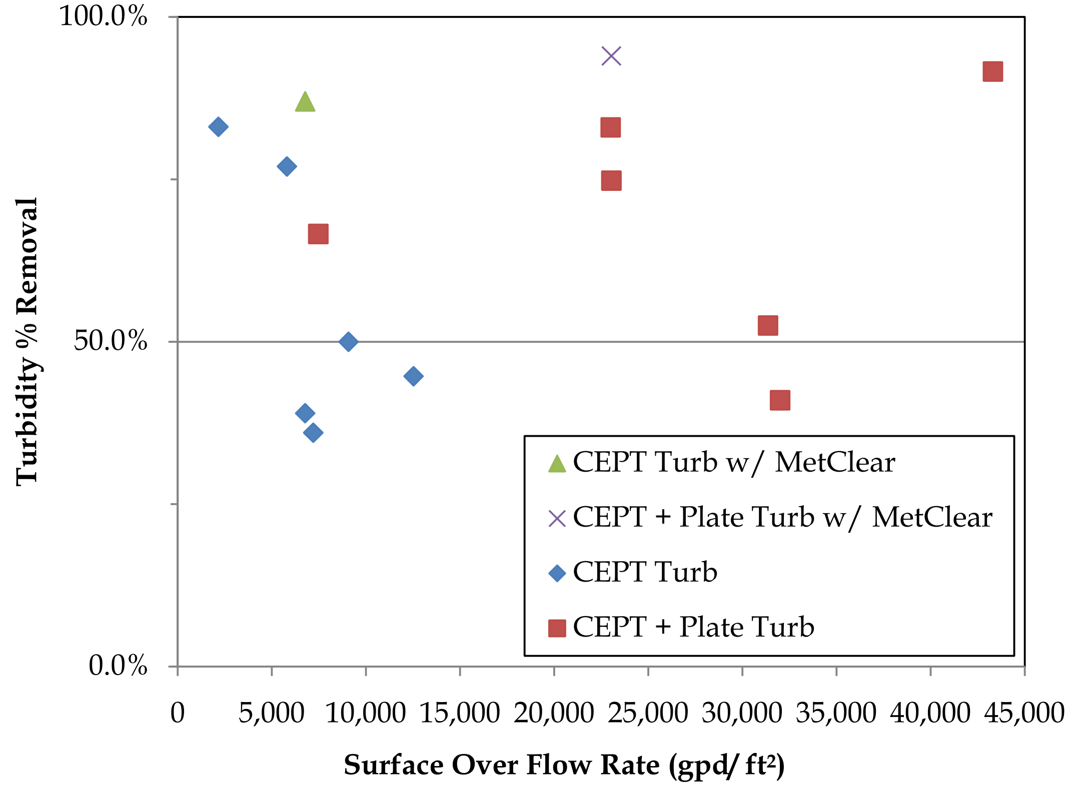


Figure 5.18 VSS Removal Rates with and without MetClear at Various SORs

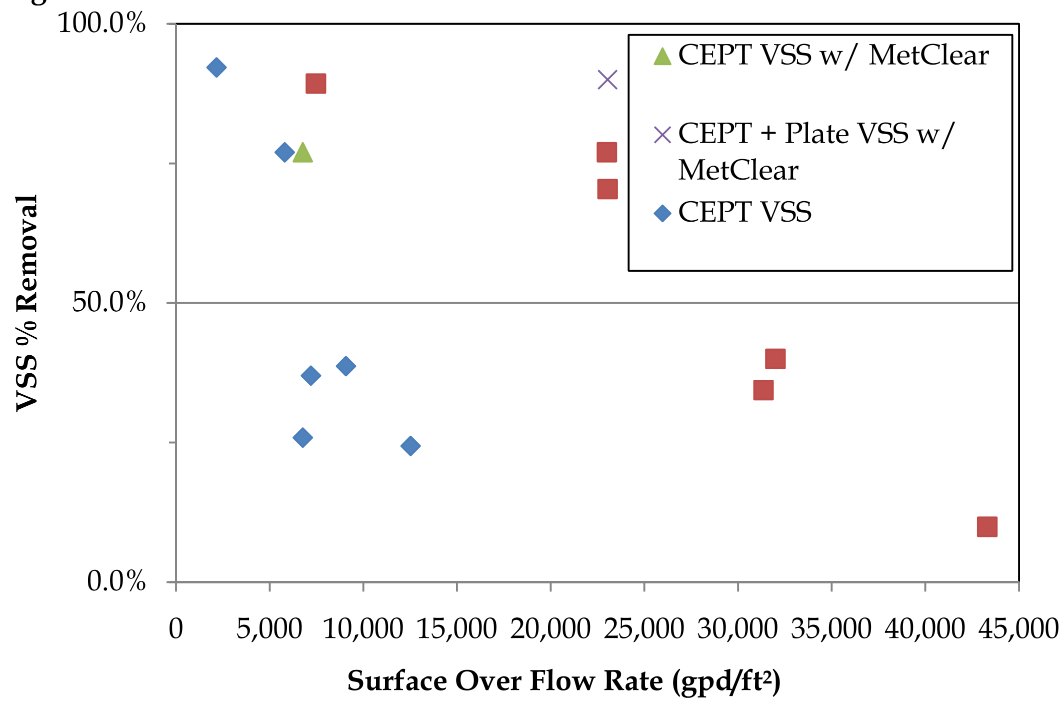


Figure 5.19 COD Removal Rates with and without MetClear at Various SORs

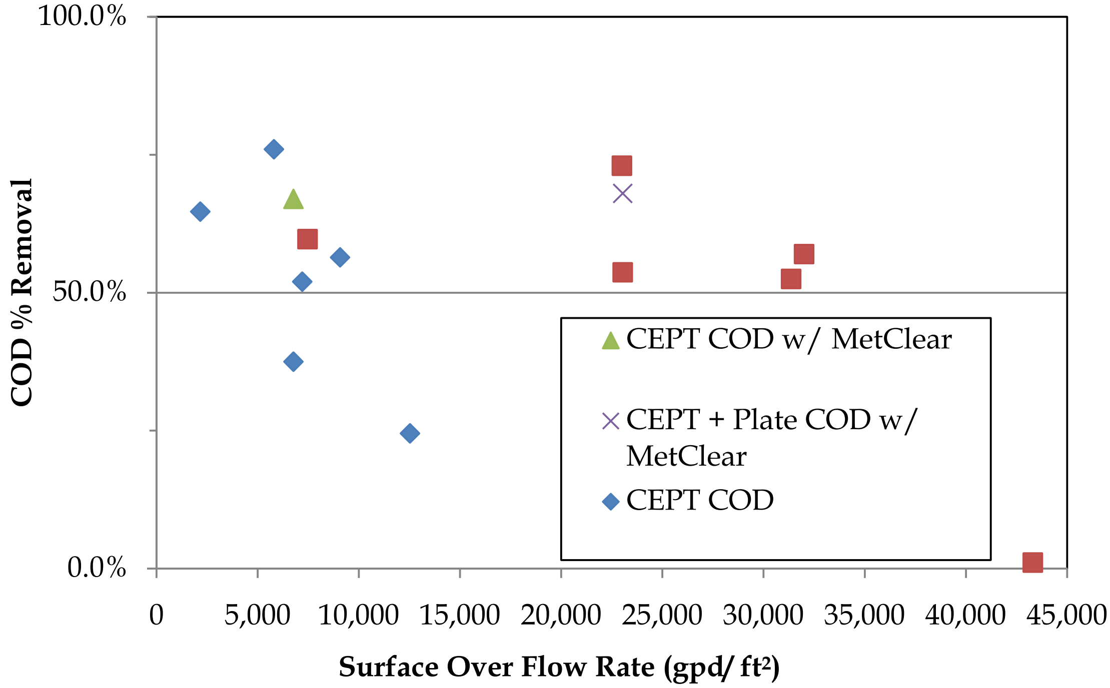


Table 5.10 Summary of PCB Data (Total PCBs)[1]

Trial	Performance Test	Influent PCB, pg/L	CEPT			CEPT+Plates		
			Effluent PCB, pg/L	PCB Removal, %	Turbidity Removal, %	Effluent PCB, pg/L	PCB Removal, %	Turbidity Removal, %
32	PAX – Low SOR	6,760	1,420	80	90	3,040	55	80
33	PAX – Med SOR	6,680	2,110	70	60	797	90	80
34	PAX – Med High SOR	12,400	4,140	70	65	4,510	65	65
35	PAX – High SOR	10,100	4,770	52	45	5,600	44	92
37	$FeCl_3$ – Med SOR	3,430	616	82	77	508	85	83
38	$FeCl_3$ – Med High SOR	4,160	1,340	68	36	N/A	--	41
41	PAX + Metclear – Med SOR	4,220	628	85	87	403	90	94

[1]MDL's for individual compounds range from 0.57 to 1.25 pg/L

Removal of conventional pollutants is summarized on **Table 5.11**. TSS removals in many of these performance trials were poor even though removal of other conventional constituents was in the expected range. The cause of this data anomaly was not found.

- COD – All composite samples showed removal of dissolved COD ranging between 27% and 54%. The coagulants appear to be capturing colloidal organics into particle sizes large enough to settle.
- Total Nitrogen – Some nitrogen removal through CEPT and CEPT+plates occurred from the organic nitrogen removed with the solids. No removal of ammonia or inorganic nitrogen was seen in the composites as expected.
- Turbidity – Turbidity for these performance trial samples appears to more closely represent the performance of the two pilot sections
- Phosphorus – Total P removal greater than 80% can be expected in optimized trials with all three of the coagulants used here.

Performance on non-conventional pollutants is summarized in **Table 5.12**. The table contains only constituents where significant removal was seen in at least one composite sample. "Significant" is defined by greater than 50% removal in any sample. Organics that showed any removal are also listed in the **Table 5.12.** Constituents that showed greater than 50% removal included arsenic (both total and dissolved), copper, chromium and lead. The Team observed significant reduction in Bis-Phthalate in trials 38 and 41 likely in conjunction with the high TSS removal in those trials.

Table 5.11 Removal of Conventional Pollutants

	Coagulant											
	PAX		**PAX**		**PAX**		**$FeCl_3$**		**$FeCl_3$**		**PAX+Metclear**	
Constituent	Trial 32		Trial 34		Trial 35		Trial 37		Trial 38		Trial 41	
	Removal, %		Removal, %		Removal, %		Removal, %		Removal, %		Removal, %	
	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates
TSS	90	87	2	-4	-14	-37	59	70	-2	13	68	81
VSS	92	89	39	34	24	10	77	77	37	40	77	90
COD, Total	65	60	56	53	24	1	76	73	52	57	87	88
COD, Dissolved	27	28	33	36	38	37	54	40	37	34	36	35
Total Nitrogen	8	11	32	1	3	0	15	12	12	9	11	10
Turbidity	83	67	50	53	45	92	77	83	63	41	87	94
Phosphorus, Total	89	82	34	43	47	35	85	89	56	61	86	89

Table 5.12 Removal Non-conventional Pollutants

	Coagulant											
	PAX		**PAX**		**PAX**		**$FeCl_3$**		**$FeCl_3$**		**PAX+Metclear**	
Constituent	Trial 32		Trial 34		Trial 35		Trial 37		Trial 38		Trial 41	
	Removal, %		Removal, %		Removal, %		Removal, %		Removal, %		Removal, %	
	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates	CEPT	CEPT+ Plates
Inorganic												
Turbidity	83	67	50	53	45	92	77	83	63	41	87	94
Arsenic, Total	72	66	36	33	29	20	66	71	38	45	59	61
Dissolved	72	64	61	60	63	62	79	78	76	75	64	62
Cadmium, Total	35	38	28	26	27	20						
Dissolved	50		11	0								
Chromium, Total	77	70			33	23						
Dissolved		66	50	43	64	59			60	55		
Copper, Total	54	49	35	32	23	19	33	39	17	15	63	80
Dissolved	31	29	27	29	18	19	23	22	24	26	81	90
Lead, Total	79	74	61	57	39	27	76	79	54	45	79	83
Dissolved	41	34	45	43	33	29	53	56	46	46	49	49
Silver, Total		79							75	75		
Dissolved			74	71	48	49						
Mercury, Total			43	34	0	0						
Misc. Organic Compounds												
Alpha-Chlordane	0	0	33	22	29	28						
Lindane	40	8										
4-Methylphenol							20					
Bis(2-Ethylhexyl)Phthalate	31	13							35	11	74	85
Phenanthrene	31	37										
Phenol	0	22										

Figure 5.20 Total Metals Removal Rates without MetClear at Various SORs for CEPT

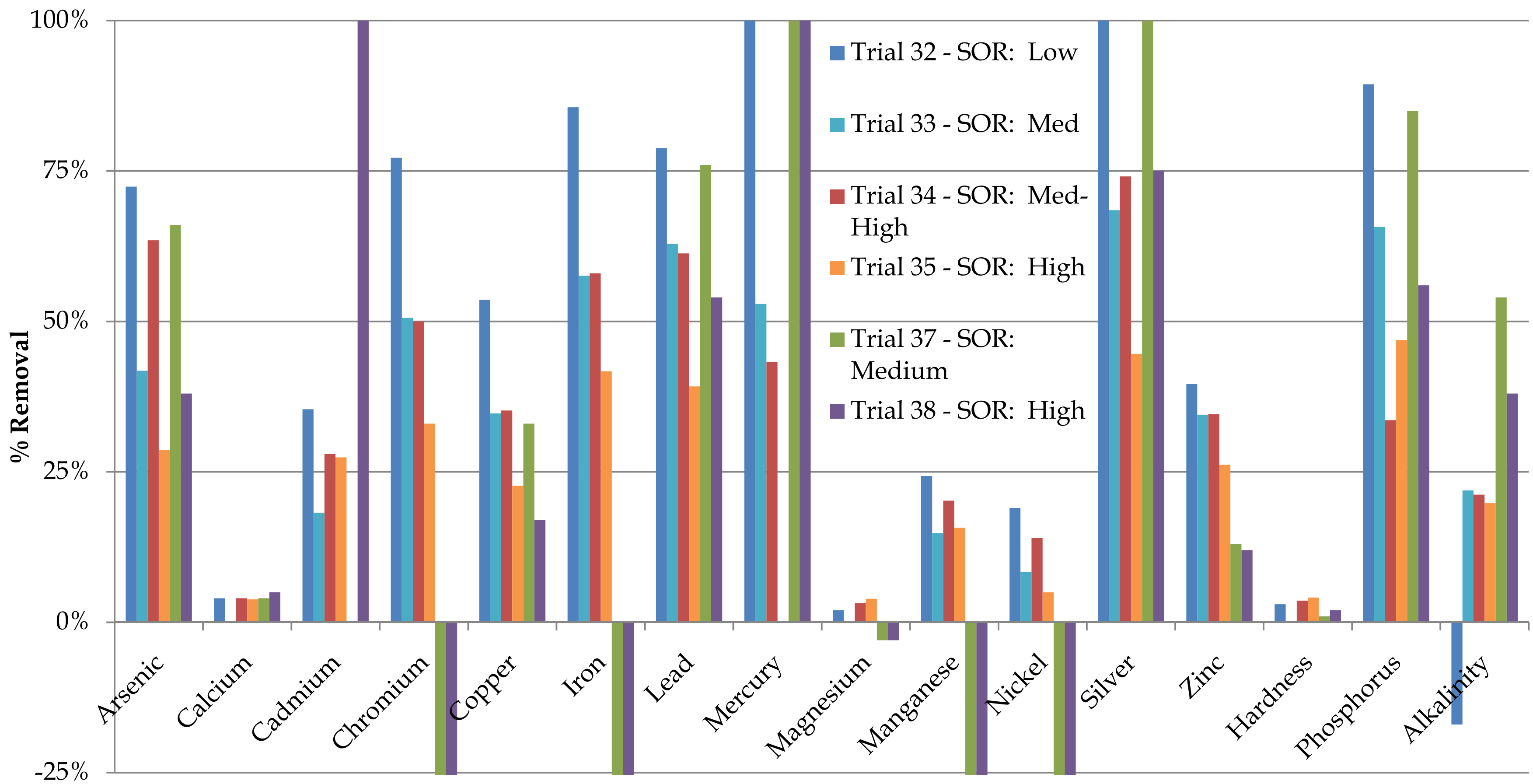


Figure 5.21 Total Metals Removal Rates with MetClear at Various SORs for CEPT

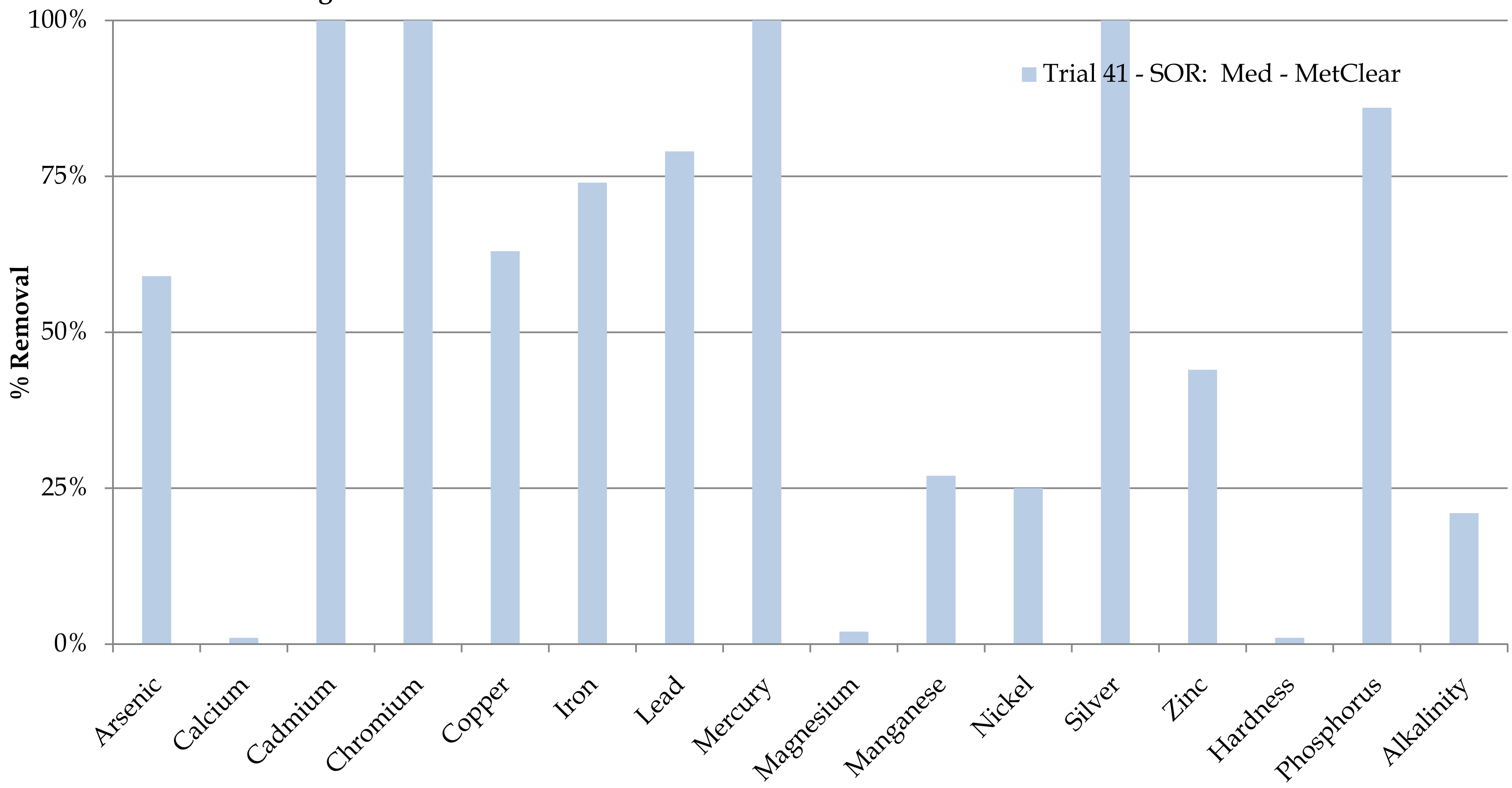


Figure 5.22 Total Metals Removal Rates without MetClear at Various SORs for CEPT + Plates

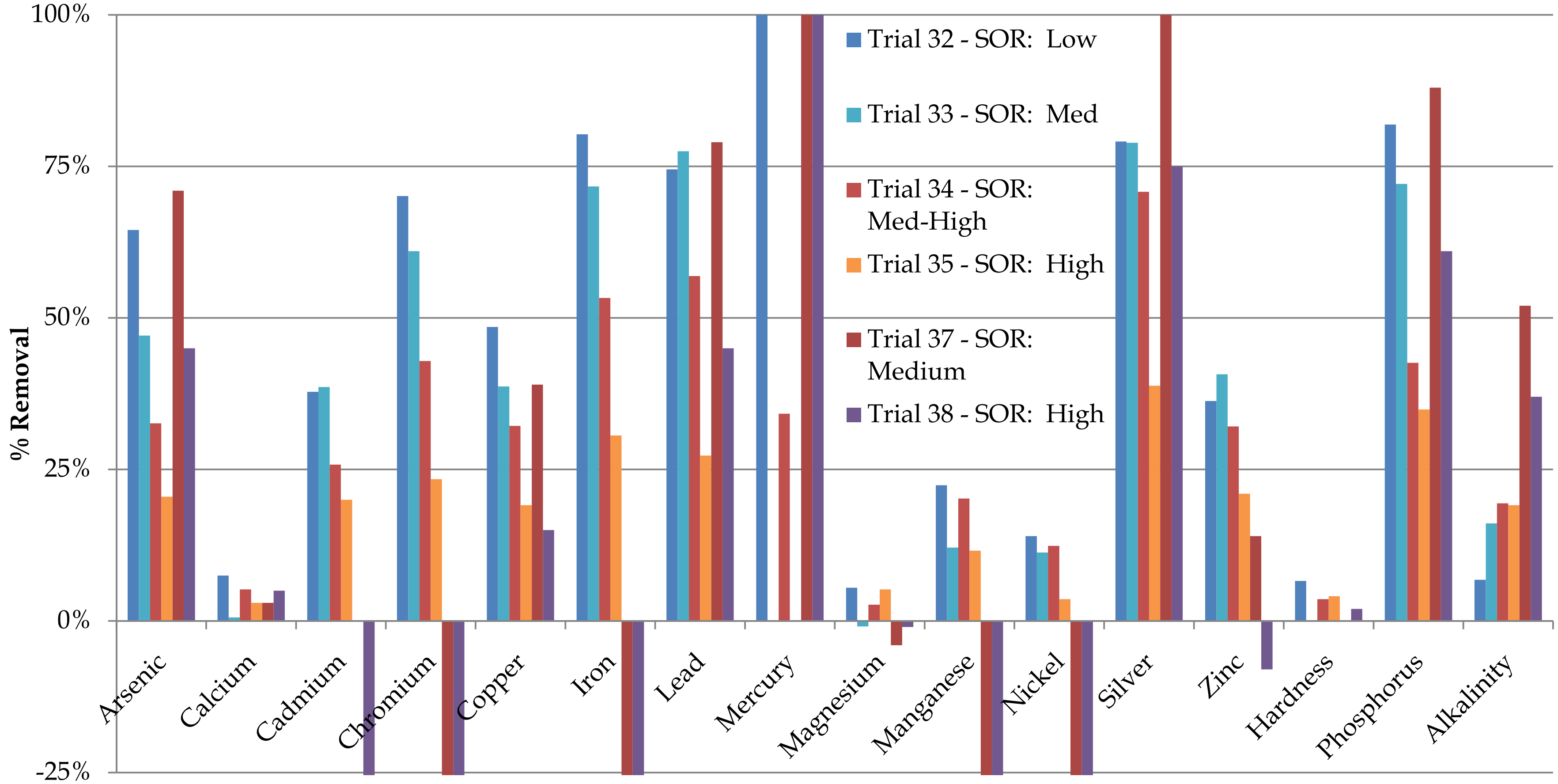
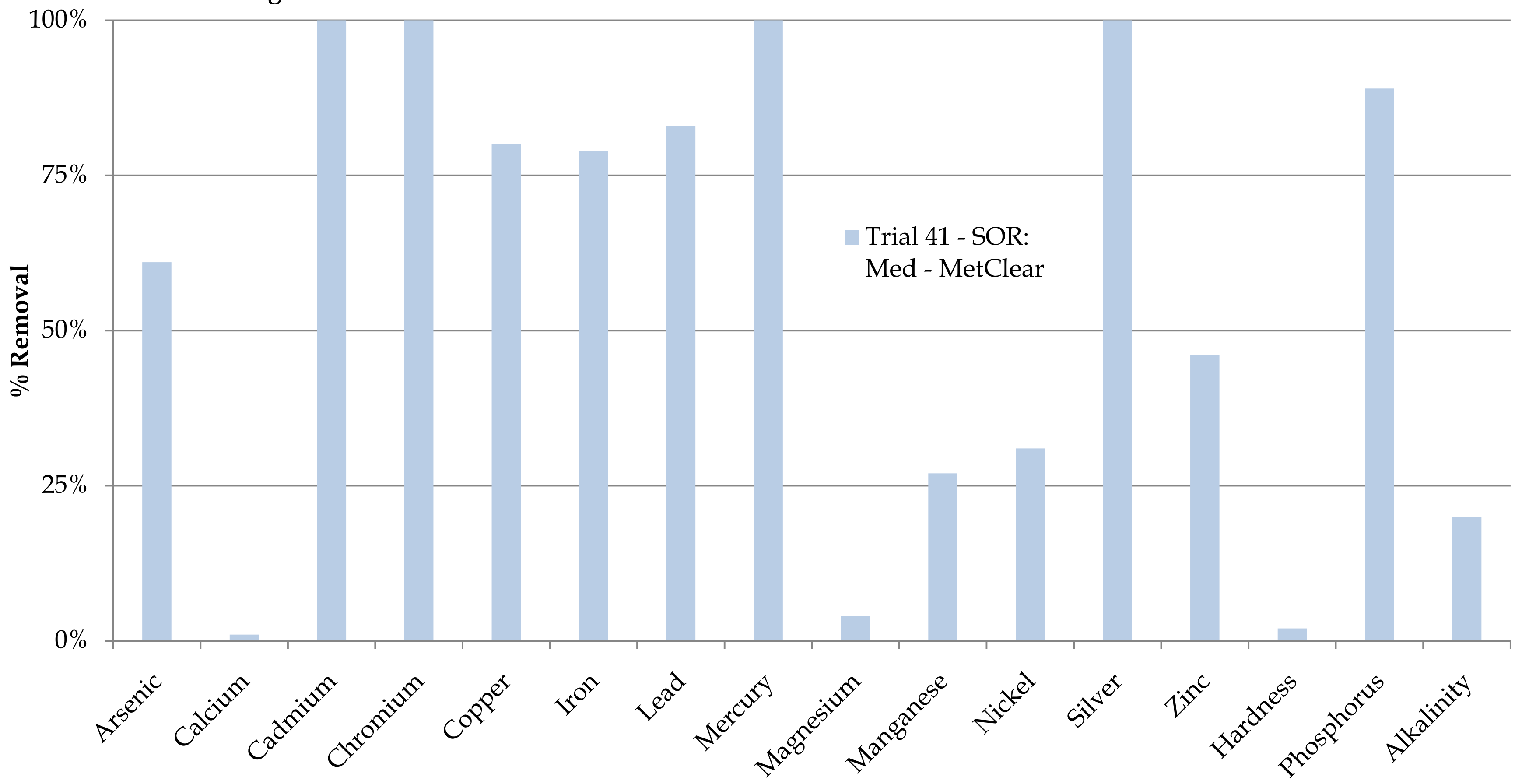


Figure 5.23 Total Metals Removal Rates with MetClear at Various SORs for CEPT + Plates



Detection limits for the performance testing are provided in **Tables 5.13, 5.14** and **5.15** for reference.

Table 5.13 Trace Metals Target Parameters and Detection Limits (µg/L)

Parameter	MDL	RDL
As (Arsenic)	0.1	0.5
Ca (Calcium)	10	50
Cd (Cadmium)	0.05	0.25
Cr (Chrome)	0.2	1
Cu (Copper)	0.4	2
Fe (Iron)	10	50
Hg (Mercury)	0.005	0.015
Pb (Lead)	0.1	0.5
Mn (Manganese)	0.1	0.5
Mg (Magnesium)	10	50
Ni (Nickel)	0.1	0.5
Ag (Silver)	0.05	0.25
Zn (Zinc)	0.5	2.5

Table 5.14 Trace Organic Compounds (1) and Reporting Limits in µg/L

Compound	MDL	RDL	Compound	MDL	RDL
1,4-Dichlorobenzene	0.048	0.00952	Dibenzo(a,h)Anthracene	0.0095	0.019
2-Methylnaphthalene	0.0095	0.019	Diethyl Phthalate	0.024	0.0476
4-Methylphenol	0.048	0.00952	Dimethyl Phthalate	0.024	0.0476
Acenaphthene	0.0095	0.019	Di-n-Butyl Phthalate	0.024	0.0476
Acenaphthylene	0.0095	0.019	Di-n-Octyl Phthalate	0.024	0.0476
Anthracene	0.0095	0.019	Fluoranthene	0.0095	0.019
Benzo(a)Anthracene	0.0095	0.019	Fluorene	0.0095	0.019
Benzo(a)Pyrene	0.0095	0.019	Indeno(1,2,3-cd)Pyrene	0.0095	0.019
Benzo(b)Fluoranthene	0.0095	0.019	Naphthalene	0.0095	0.019
Benzo(g,h,I)Perylene	0.0095	0.019	Pentachlorophenol	0.095	0.19
Benzo(k)Fluoranthene	0.0095	0.019	Phenanthrene	0.0095	0.019
Benzyl Alcohol	0.048	0.0952	Phenol	0.048	0.0952
Benzyl Butyl Phthalate	0.048	0.0952	Pyrene	0.0095	0.019
Bis(2-Ethylhexyl)Phthalate	0.024	0.0476	Bis(2-ethylhexyl)adipate	0.1	0.2
Caffeine	0.0095	0.019			
Chrysene	0.0095	0.019			

Table 5.15 Trace Organics Compounds (2) and Reporting Limits (μg/L)

Compound	MDL	RDL
4,4'-DDD	0.0047	0.00943
4,4'-DDE	0.0047	0.00943
4,4'-DDT	0.0047	0.00943
Aldrin	0.0047	0.00943
Alpha-BHC	0.0024	0.00472
Alpha-Chlordane	0.0024	0.00472
Beta-BHC	0.0024	0.00472
Delta-BHC	0.0024	0.00472
Dieldrin	0.0047	0.00943
Endosulfan I	0.0047	0.00943
Endosulfan II	0.0047	0.00943
Endosulfan Sulfate	0.0047	0.00943
Endrin	0.0047	0.00943
Endrin Aldehyde	0.094	0.0189
Gamma-BHC (Lindane)	0.0024	0.00472
Gamma-Chlordane	0.0024	0.00472
Heptachlor	0.0024	0.00472
Heptachlor Epoxide	0.0024	0.00472
Methoxychlor	0.024	0.0472
Toxaphene	0.047	0.0943

An additional feature of the performance testing was to evaluate the effluent for suitability for UV disinfection using absorption of an UV wavelength of 254 nm as an indication. Results were only gathered on samples from the $FeCl_3$ and PAX plus MetClear trials and those results are summarized in **Table 5.16**. For both CEPT and CEPT+plates, the UV 254 transmisivities for both the diluted primary influent and the effluent were over 66%. A slight increase in transmittance was noted on all runs across the unit. Transmittance of 66% at 254 nm and above is typically what is seen in an activated sludge effluent, which suggests that the UV disinfection characteristics may be dominated by the secondary effluent dilution.

Other columnated beam testing performed on effluents from wet weather treatment facilities using CEPT+plates and high rate clarification (Toronto and Bremerton Eastside) have produced results indicating ultraviolent transmittance (UVT) ranges from 40 to 60%. Accompanying these tests with columnated beam testing and full scale performance showing a Fecal Coliform of 200 CFU/100ml could be achieved at a dose of 30 m x Ws/cm^2. Based on these results, the pilot plant effluent UV should be effective in meeting the Fecal Coliform requirement of 400/100 ml currently in the CSO plant discharge permits at a relatively low UV dose.

Table 5.16 Results of Absorption of UV-254

Trial	Coagulant		Absorptivity (cm^{-1})	Removal of Absorptivity or Absorbance	Transmittance	Increase of Transmittance	TSS (mg/L)	Removal of TSS	Turbidity (NTU)	Removal of Turbidity
37	$FeCl_3$	**Influent**	0.18	NA	66%	NA	32	NA	19.2	NA
		CEPT	0.0989	45%	80%	21%	13	59%	4.51	77%
		Plates	0.0986	45%	80%	21%	9.55	70%	3.21	83%
38	$FeCl_3$	**Influent**	0.168	NA	69%		35.6	NA	19.1	NA
		CEPT	0.117	30%	76%	12%	36.2	-2%	12.2	36%
		Plates	0.116	31%	77%	13%	31	13%	11.3	41%
41	PAX18 +MetClear	**Influent**	0.18	NA	66%	NA	40.7	NA	16.6	NA
		CEPT	0.135	25%	73%	11%	13	68%	2.18	87%
		Plates	0.134	26%	74%	11%	7.6	81%	0.988	94%

5.8 Hydrograph Events

Two simulated storm events were tested during Trials 46 and 47 to determine how the CEPT and CEPT+plates technologies would respond to dynamic conditions typical of wet weather. **Figure 5.24** shows the surface overflow rates, as well as the turbidity removal percentages, over the course of Trial 46. For this run, the SORs peaked at approximately 35,000 gpd/ft^2 and 6,000 gpd/ft^2 for the CEPT+plates and the CEPT section respectively. These SOR values did not push either zone into failure (as defined as removal rate dropping below 50%), as shown by the consistently high removal rates.

For Trial 47, as shown in **Figure 5.25**, the SORs peaked at approximately 52,000 gpd/ ft^2 and 10,000 gpd/ ft^2 for the CEPT+plates and the CEPT section respectively. These SOR values were much more aggressive and did produce failure during the peak of the simulated storm event. Both clarification zones did recover rapidly once the flow was lowered. The full data from all hydrograph tests can be seen in **Appendix B**.

Based on the results of these trials, both technologies appear to handle dynamic conditions well. Only during extreme flow conditions were the units pushed to failure.

Figure 5.24 Turbidity Removal percentages and Surface Overflow Rates for Hydrograph Test – Trial 46

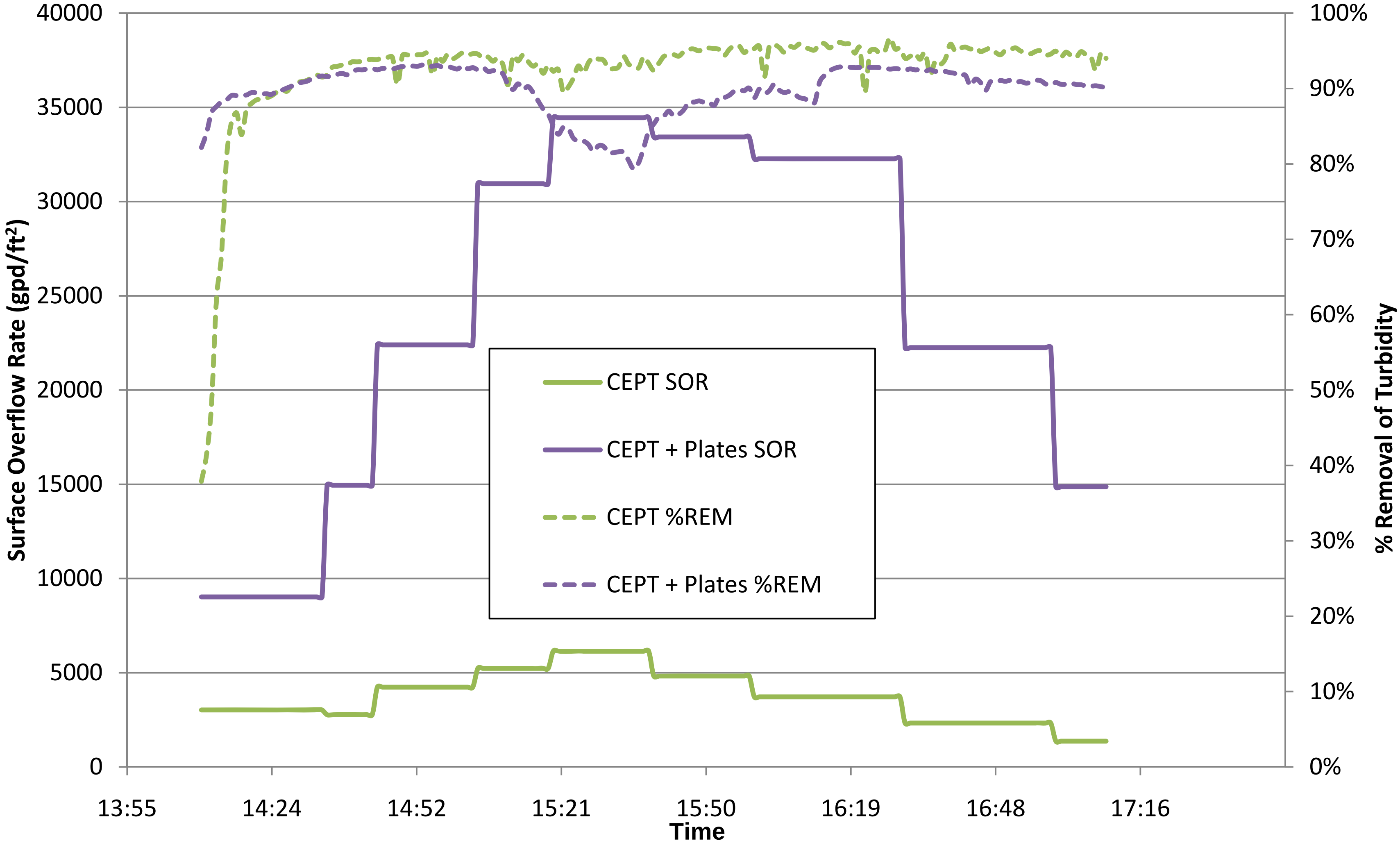
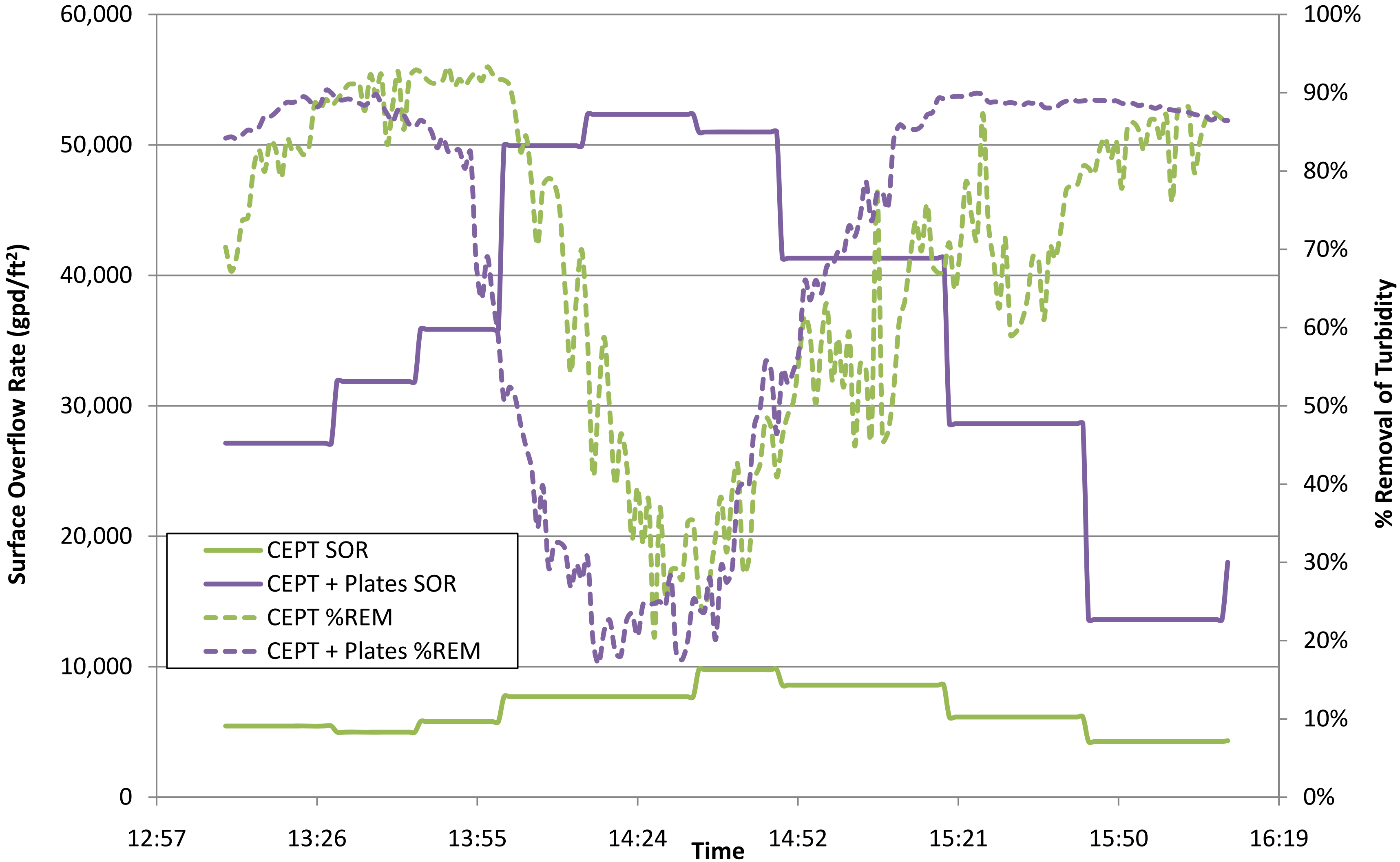


Figure 5.25 Turbidity Removal percentages and Surface Overflow Rates for Hydrograph Test – Trial 47



A summary of the performance for the two processes on non-steady state events is found in **Table 5.17**

Table 5.17 Summary of Performance during Non-steady State Events

	CEPT	CEPT + Plates
Low SORs (Trial 46)		
SOR at > 50% TSS removal, gpd/ft^2	6,000	21,000
TSS Removal at Event Peak, %	88	62
Influent Mass Removal for Entire Event		
Based on Flow Proportional, Composite sample, %[1]	92	90
Based on integrating grab samples, %[2]	90	88
High SORs (Trial 44)		
SOR at > 50% TSS removal, gpd/ft^2	8,000	35,000
TSS Removal at Event Peak, %	30	20
Mass Removal for Entire Event		
Based on Flow Proportional Composite sample, %[1] (TSS)	41	67
Based in integrating grab samples, %[2] (TSS)	75	65

[1] NPDES permit for CSO Outfall requires Flow Proportional composites are individual samples collected into a single container and analyze as one sample. The Permit requires the composite sample should represent the entire event.

[2] Calculated using flow times estimated TSS concentration of individual grab samples integrated over the entire 3 hour event.

For both trials, the overall removal for the entire simulated event was above the required 50% even though both the CEPT and CEPT+Plates sections failed for approximately one hour at the height of the three hour event.

5.9 Consolidated Data

Combining the data from approximately 36 trial runs performed throughout the course of this project, a relative performance comparison of the CEPT and CEPT+plates technology was developed. Specifically, the removal efficiencies of the technologies for TSS, COD and turbidity at varying surface loading rates were compared.

The results of this relative comparison are provided in **Figures 5.26, 5.27** and **5.28**, respectively.

Figure 5.26 TSS Removal Summary

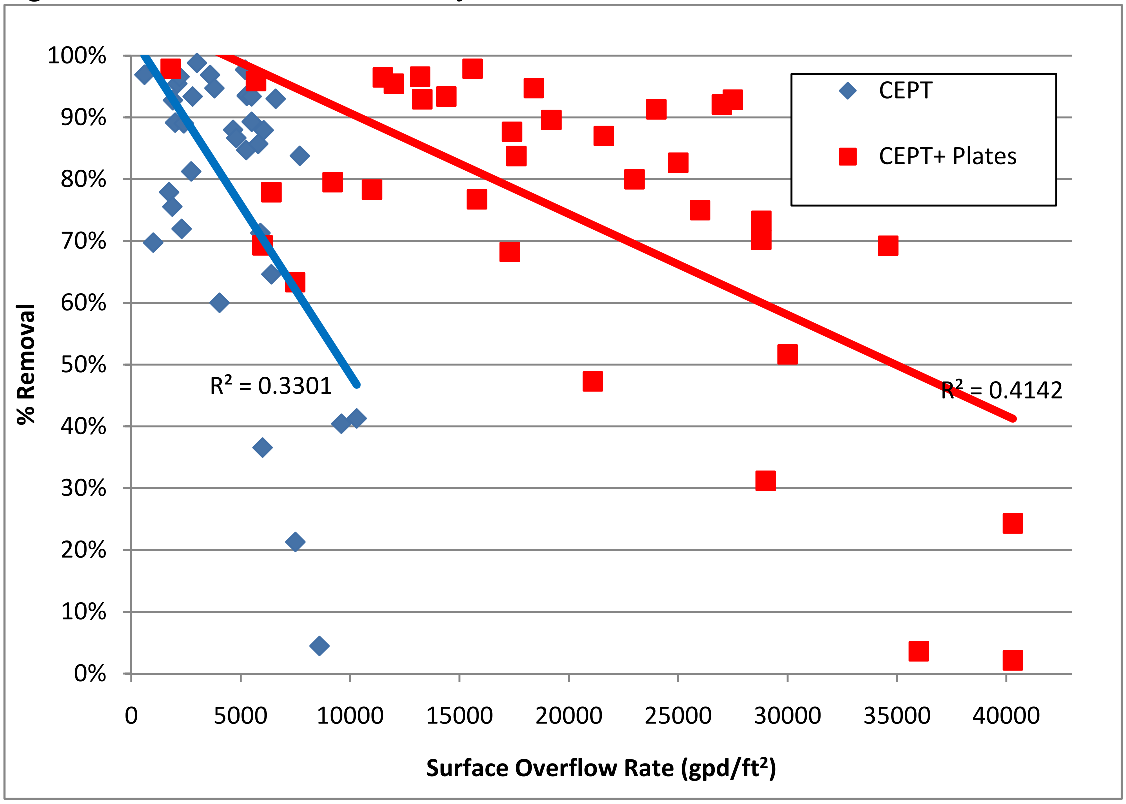


Figure 5.27 COD Removal Summary

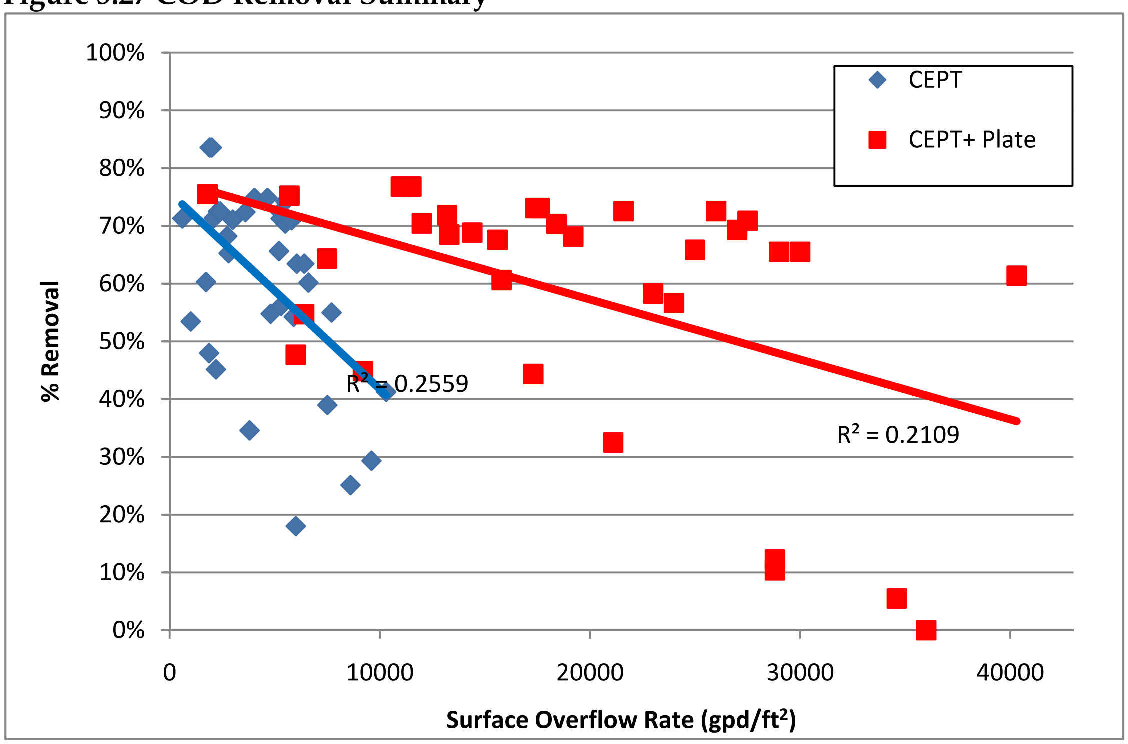
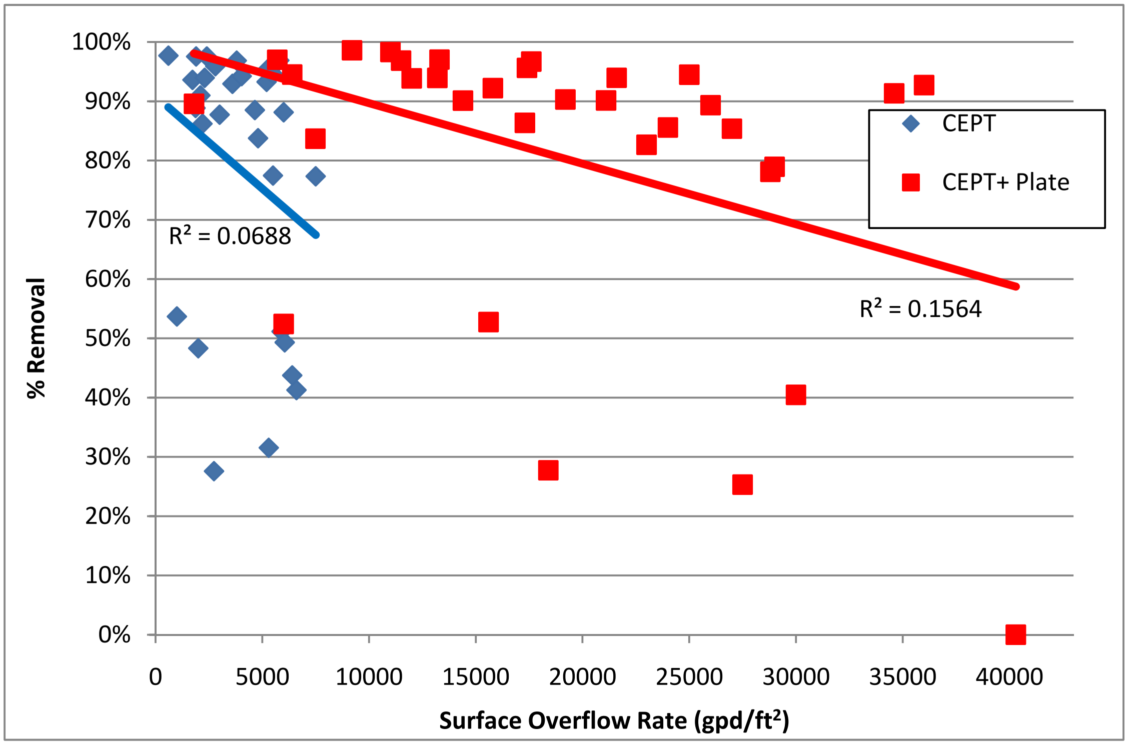


Figure 5.28 Turbidity Removal Summary



These figures include a general trend line (linear regression) for all the pilot data. Summary observations for the two technologies are found in **Table 5.18**

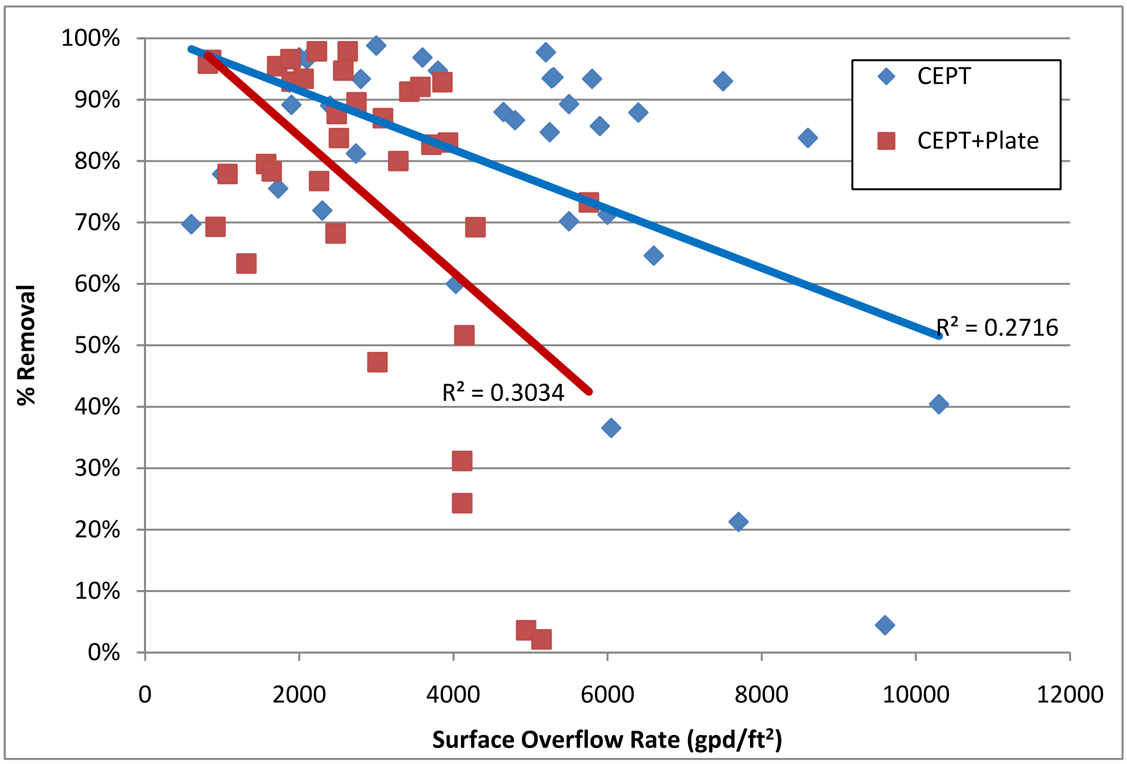
Table 5.18 Comparison of CEPT and CEPT+plates

Item	CEPT	CEPT+plates	Ratio of Plate to CEPT Performance
Removal at SOR = 5,000 gpd/ft²			
TSS, %	75	98	≈ 1.3
COD, %	58	72	≈ 1.2
Gross Surface Area			
Settling area of pilot unit, ft²	10	6.8	N/A
Peak SOR with >50% TSS Removal is achieved, gpd/ft²	7,500	27,000	3.6

The CEPT+plates exhibited significantly better performance with respect to both pollutant removal and performance at high SORs compared with the CEPT technology. At SORs where conventional CEPT was effective (<5,000 gpd/ft²), the plates increased TSS and COD removal by 30% and 20%, respectively. The performance goal of 50% removal of TSS was achieved by CEPT+plates at SORs that were 3 to 4 times higher than CEPT alone. This data suggests that the added collection area provided by the lamella plates does increase the efficiency of the CEPT technology, especially in terms of removal per unit area of the clarifier.

To further investigate this trend, and to understand how plates impact the removal efficiency, the same data was graphed using the projected area of the lamella plates for calculating the SOR. This comparison using a projected plate surface area of 65 ft^2 (instead of the gross clarifier are of 6.8 ft^2) is shown in **Figure 5.29.**

Figure 5.29 TSS Removal Based on Projected Plate Area



Summary observations based on this plot are found in **Table 5.19.**

Table 5.19 Comparison of CEPT and CEPT+plates (Projected Area)

Item	CEPT	CEPT+plates	Ratio of Plate to CEPT Performance
Projected Plate Area			
Projected settling area of pilot unit, ft^2	10[1]	65	N/A
Peak SOR where >50% TSS Removal is achieved, gpd/ft^2	7,500[1]	2,900	0.4

[1] The projected area of the pilot for CEPT was taken as the gross clarifier surface area. This was done for comparison purposes.

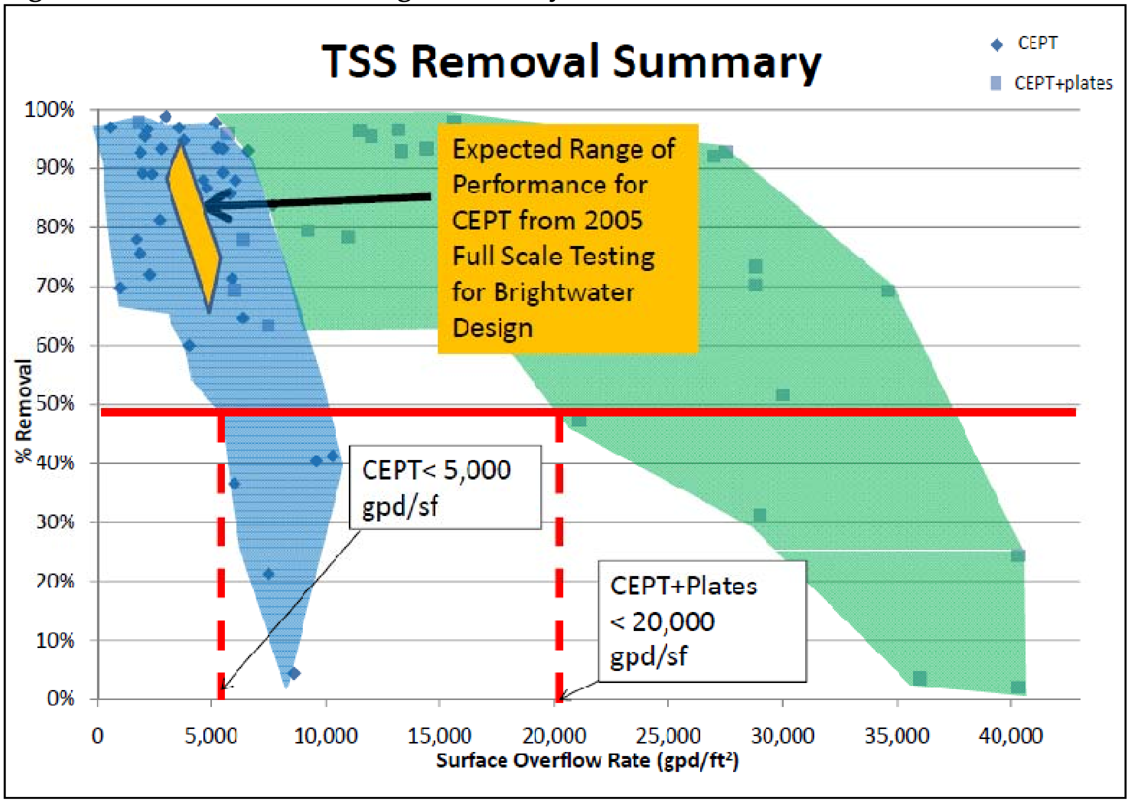
The graph and the table show that the on a projected plate area basis, the CEPT outperforms the CEPT+plates. The reason for this is that while the plates increase the total area of the clarifier, they also contribute to turbulence within the clarifier which can reduce the efficiency of that unit. This analysis, combined with the analysis on using gross surface area, indicates that while the addition of plates can increase the total efficiency of the clarifier, there is some in efficiency associated with the increased surface area. In other words, for each square foot of plate area added to the clarifier, only a fraction of the plate area will be translated into increased performance.

5.10 Loading Rates

One objective of the study was to establish the maximum loading rate at which each technology will consistently meet potential discharge requirements. Trials were conducted to demonstrate the maximum sustainable SOR meeting greater than 50 percent removal of TSS. The 50 percent removal requirement is assumed to be continuous and not the average for a CSO event.

Figure 5.30 is a scatter plot of the entire TSS removal data set. Due to variations in chemical addition strategy, influent characteristics, equipment calibration issues, and build up of sludge in the unit and plates the scatter plot covers a broad range. This broad range is typical of full-scale plants as well, because of the presence of the same variables.

Figure 5.30 TSS Removal Range Summary



Based on the scatter plot, the following SORs are recommended for design values:

- **CEPT < 5,000 gpd/ft²**
- **CEPT + Plates <20,000 gpd/ft²**

For all trials operated at or below this range, regardless of other operating conditions, the technologies were able to meet the 50% removal of TSS design criteria. Operations in excess of these values are possible, and were shown to provide the requisite treatment at times, but the performance is less predictable and reliable. The design values shown above represent conservative estimates for SOR loading rates for full-scale design.

Also plotted on **Figure 5.30** are the the results from the full-scale testing done at the South Plant in 2005 [Brightwater Final Design; Technical Memorandum Phase 3, Task 3.44; October 2005]. The objective of the South Plant study was to project performance for CEPT in the Brightwater design. The 2005 South Plant full-scale results fall within the performance seen in this pilot study.

Section 6
Summary and Interpretation of Results

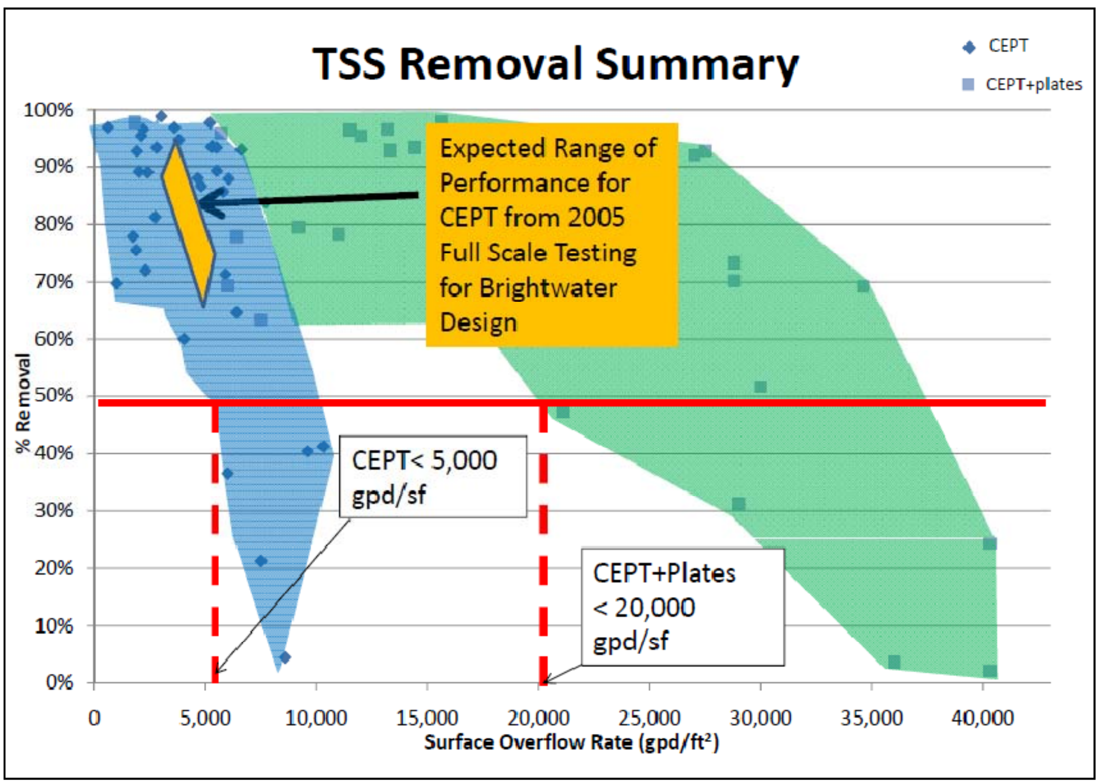
Based on the results reported in Section 5, the primary and secondary objectives of the pilot project were revisited. A summary response for each objective is provided below.

6.1 Primary Objectives

1. *Evaluate clarification technologies for effectiveness (vs. conventional primary treatment) at removing TSS and COD over a range of surface overflow rates and operating conditions:*

   Both the CEPT and CEPT technologies were operated over a wide range of loading rates. A summary graph of the trials indicates that the CEPT can be operated at approximately twice the rate of conventional primaries and CEPT+Plates can be operated at approximately fifteen times the rate conventional primaries.

   Figure 6.1 TSS Removal Summary



2. *Establish maximum loading rate at which each technology will consistently meet potential discharge requirements:*

For consistent removal of greater than 50% TSS, the SOR design criteria are as follows:

- CEPT < 5,000 gpd/ft^2
- CEPT + Plates <20,000 gpd/ft^2

Loading rates in excess of this are possible, but performance becomes less reliable at higher rates.

3. *Optimize chemical addition and assess sensitivity of technologies to variations in influent characteristics:*

   The optimization of chemical addition for the pilot unit was accomplished via the incorporation of a mechanical mixer for coagulant addition and a compressed air assisted injection for the polymer. For the pilot unit, the optimal chemical dosing levels were:

   Table 6.1 Chemical Dose

Coagulant	Dose, mg/L
PAX	12
$FeCl_3$	40
PAX plus Metclear	12 plus 25

   Testing for the sensitivity to variations in influent characteristics was accomplished with two storm events (Hydrograph Testing). The hydrograph testing showed that the systems responded well to variations in influent flow rate and loading characteristics provided that the flow rates did not exceed the peak capacity of the units. When capacity was exceeded, the performance dropped significantly.

4. *Examine the impact of pre-chlorination on chemical addition and performance through jar testing and, if necessary, field testing:*

   The impacts of pre-chlorination were abandoned as an objective due to two factors specific to the field installation.

   - All jar tests used DI as a dilution source. The CI dilution water for the pilot carried a chlorine residual of 5-6 mg/l and fell to near zero once blended with the primary influent. Jar tests would not be representative of how pre-chlorination impacted pilot performance.
   - The detention time of the pilot unit is much less than full scale CSO installations because most wet weather plants incorporate some storage

into their process. Information on the effects of pre-chlorination from the pilot would not be useful in a full scale application.

5. *Evaluate effluent for suitability for UV disinfection:*

   The effluent produced by the CEPT and the CEPT+plates technologies with UV-254 absorbance and transmisivity in the range required for UV disinfection. A dose of 30 m x Ws/cm2 should be sufficient for meeting the Fecal Coliform requirement of 400/100 mL

6. *Assess potential for automatic control of chemical addition:*

   The pilot chemical addition was manually flow paced based on the optimum dosage developed in the chemical optimization phase. The dose required did not change because of influent TSS, turbidity or SOR. Therefore, flow simple, automated flow pacing is a reliable approach over the range of inlet conditions seen in the pilot. More complex flow and turbidity feedback control will not be necessary to achieve satisfactory performance.

7. *Identify potential operation and maintenance issues:*

   The pilot unit showed reduced performance when the sludge blanket was allowed to accumulate, this was due largely to the shallow depth of the pilot unit. The full-scale facility will require a deeper clarifier more typical of wet weather facilities to avoid problems associated with sludge accumulation.

   Loss of coagulant testing showed effluents from both sections began to degrade within approximately a half a detention time in the unit but recovered equally as fast after the coagulant was restarted.

   There is a great potential for scale buildup and ballast/lamp failure in the UV disinfection for a limited use facility.

8. *Monitor influent and effluent for established list of conventional, metals and organics parameters:*

   Influent and effluent were monitored for these parameters as part of Trials 32-35, 37, 38 and 41.

6.2 Secondary Objectives

1. *Provide information that will help develop a start-up strategy for full-scale CSO treatment facilities:*

   Most full scale facilities will fill provide storage as well as treatment. All pilot performance testing was done from a full tank start since the pilot configuration did not have a storage component. With no storage available, this objective was not addressed in the final study

2. *Provide qualitative information on the need for fine screening for the selected alternatives and degree of grit removal:*

   The pilot feed was screened prior to use by means of 5/8-inch screening and aerated grit removal. Noticeable debris in the pilot unit was observed during many of the runs. A minimum screening of 1/4 to 3/8-inch and grit removal prior to treatment on full scale would be prudent to reduce shut down and clean-up needs

3. *Characterize the sludge thickening/storage characteristics:*

   During the piloting runs sludge accumulated from both conventional solid production and chemical solids production. Sludge was analyzed as part of the performance runs. Sludge concentration was consistently in the 2% TSS range. Sizing of the treatment units will be done both from a storage perspective and for sludge accumulation. With the higher volumes/depth of basin taken into account the sludge should be thickened to the 2 to 4% range for removal or future discharge back to West Point.

4. *Determine the cleanup needs and characterize the susceptibility to plugging and fouling:*

   Cleanup after the piloting runs did indicate that some debris not captured by prescreening and grit removal could cling to the plates at high SORs. The sludge blanket at the bottom of the clarifier being resuspended corresponding to high velocities. At the loading rates and trial run times in this study, very little cleanup was needed and was accomplished by hosing down the plates after each piloting run.

5. *Determine what range of chemical dosing is most effective and the relevant detention time*:

   See response to Primary Objective 3.

6. *Evaluate the variability of effluent with respect to influent turbidity:*

   Dilution testing showed that with varying dilution (decreasing influent turbidity), the effluent quality stayed consistent.

7. *Identify the percent of metals bound in TSS:*

   Suspended solids removal data during performance tests was unreliable. Therefore, turbidity is used as a surrogate for TSS. In general, the higher the turbidity removal, the higher the trace metals removal. Turbidity removals of 70% and above resulted in greater than 70% removal of arsenic, chromium, lead and silver. Removals of dissolved metals were significantly less as expected, although some removal was observed in all trials. This removal was likely due to the coagulant and polymer increasing the size of the colloidal particles containing metals that could then settle. Greater than 80% turbidity and copper removal was achieved in Trail #41 using the Metclear in addition to PAX and Metclear did increase all metals removal.

8. *Demonstrate the maximum sustainable surface overflow rates (SOR), while meeting greater than 50% removal of TSS.*

For consistent removal of greater than 50% TSS, the SOR design criteria are as follows:

- CEPT < 5,000 gpd/ft^2
- CEPT + Plates <20,000 gpd/ft^2

Loading rates in excess of this are possible, but performance becomes less reliable at higher rates.

6.3 Performance Summary

The CSO Pilot performance is summarized in **Table 6.1.**

Table 6.2 Pilot Performance Summary

Issue	Performance Goal	Pilot Performance
CEPT vs. CEPT+plates	50 percent TSS removal continuous	• CEPT+plates consistently achieved 50% removal at loading rates 4 times CEPT • Pilot met performance goals at an SOR of 5,000 and 20,000 gpd/ ft^2 for CEPT and CEPT+plates, respectively
Loading Rates	1.Identify SOR's based on gross area where requirements are met 2. Relate these SOR Rates to plate design	• The plates in this study increase the settling area of the CEPT clarifier tenfold, but yield a fourfold increase in SOR that results in meeting the project objectives. • *Example: A conventional clarifier with CEPT and 1,000 ft^2 could be expected to remove 50% TSS at a SOR of 5,000 gpd/ ft^2 or a flow of 5 MGD. A CEPT+plates clarifier with the same gross surface area of 1,000 ft^2 but with a projected plate area of ten times the surface area could be expected to achieve the same performance at 20,000 gpd/ ft^2 or 20 MGD; not ten times the capacity of the CEPT clarifier.*
Chemical Optimization	Define minimum dosages that meet the removal requirements at a wide range of SORs	• Effective PAX and Ferric chloride doses were 12 and 40 mg/L, respectively. These doses may be lower on real CSOs when the alkalinity is much lower than the blends used in the study.
UV Disinfection	Determine if an effluent can be produced with a	• Yes, pilot plant effluent percent transmittance was similar to a normal secondary effluent. Based on the limited

	low enough turbidity to make UV feasible?	sampling in this study, UV should be effective in meeting the Fecal Coliform requirement of 400/100 mL currently in the CSO plant discharge permits at a relatively low UV dose.
Issue	**Performance Goal**	**Pilot Performance**
Control, Operation and Maintenance	Identify major issues, if any, that will impact the design of a full scale facility	• Pilot showed reduced performance when sludge blanket was allowed to accumulate, due largely to the shallow depth of the pilot unit. The full-scale facility will require a deeper clarifier more typical of CSO facilities to avoid problems with sludge accumulation. • Loss of coagulant testing showed effluents from both sections began to degrade within approximately a half a detention time in the unit but recovered equally as fast after the coagulant was restarted.
Removal of Conventional Pollutants, Metals and Organics	• COD • Phosphorus • Metals • Organics	• All composite samples showed removal of dissolved COD ranging between 27% and 54% for both CEPT and CEPT+plates at the effective SOR's. • Total P removal greater than 80% can be expected in optimized trials with either PAX or ferric chloride used as a coagulant. • Constituents that showed greater than 50% removal in both the CEPT and CEPT +plates include arsenic (both total and dissolved), copper, chromium, silver and lead. • There was significant reduction in PCBs associated with turbidity removal and some removal of Bis-Phthalate in a few trials.

Section 7
Scale-Up Considerations

This section addresses the implications of applying the piloting results to a full-scale CSO treatment facility. The section contains information on existing full-scale plants, including the only known wet weather treatment facility to employ lamella plates in North America, and commentary on issues such as solids handling, storage and disinfection.

7.1 Basis of Design for Full Scale Facilities

Based on the data reported in Section 5 and summarized in Section 6, the recommended design criteria are summarized in **Table 7.1.**

Table 7.1 Recommend Design Criteria

Clarifier Design	CEPT	CEPT+Plates
TSS Removal, %	> 50	> 50
SOR based on Gross Clarifier Surface Area, gpd/ft^2	5,000	20,000
SOR based on Projected Plate Surface Area, gpd/ft^2	N/A	3,000
Flocculation		
Detention Time, min	> 7	> 7
G Value, sec^{-1}	10 to 90	10 to 90
Chemical Dose		
PAX Coagulant, mg/L as Al		
Normal	12	12
Range	4[1] - 16	4[1] - 16
Nalco Anionic Polymer, mg/L	1.5	1.5
Disinfection		
Fecal Coliform, CFU/100mL	400	400
UV Dose, m*Ws/cm^2	30	30
Waste Sludge Concentration, %TSS	< 2	< 2

[1]Low end of dose range expected to be effective on lower alkalinity CSO such as experienced at other Puget Sound high rate sedimentation facilities

Table 7.1 contains no recommendation for clarifier depth, although most high-rate, full scale facilities have clarifier side water depths of 16 to 20 feet to:

- Accommodate a significant sludge blanket buildup during an event

- Provide for some sludge thickening
- Provide storage for small CSO events
- Provide disinfection contact time

On the pilot unit, the clarifier was relatively shallow with an 8 foot side water depth. The shallow depth created a few issues. If the sludge blanket was not properly managed and wasted in between runs, turbulence within the unit re-suspended solids, which reduced efficiency. Additionally, if the blanket was allowed to accumulate, it became more difficult to clean and restart the pilot unit. For a full-scale plant, a side water depth of at least 16 to 20 feet is recommended.

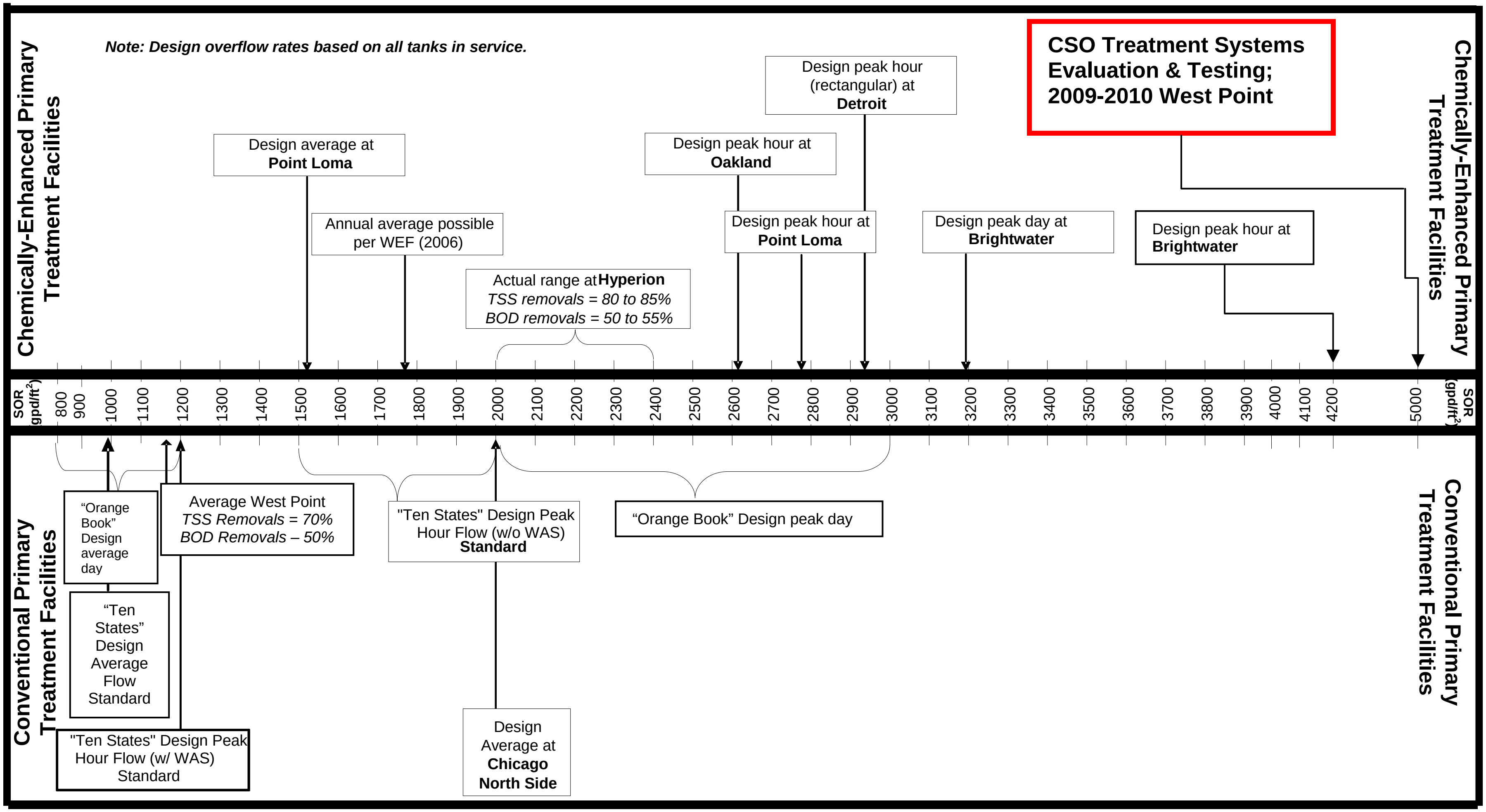
7.2 Comparisons with Full Scale Installations

There are very few examples of full-scale installations using CEPT or CEPT+plates to treat CSOs. The following is a summary of some that experience.

7.2.1 CEPT

A graph of typical SOR design ranges for conventional clarifiers and CEPT are provided in **Figure 7.1.** Also included on the graph is the recommended design range for CEPT based on the pilot study. This graph shows that the loading rate and the recommended design SOR from the pilot are higher than the previous design criteria used on other full-scale plants including the Brightwater design. The recommended CEPT SOR in intermittent service is 20 percent higher than the peak hour overflow rate for Brightwater. Using the Brightwater peak hour design as a low end standard and the operations of the pilot plant as a high end standard, a reasonable peak condition design criteria for a CSO treatment facility where removals greater than or equal to 50 percent are required is an SOR of 4,200 and 5,000 gpd/ft^2.

Figure 7.1 Standard and Actual Design Surface Overflow Rates for Conventional Primary Clarifiers (bottom) and CEPT Primary Clarifiers (top) show ranged used in this study.



7.2.2 CEPT+Plates

The Gold Bar Wastewater Treatment Facility in Edmonton, Alberta is the only full-scale CEPT+plates plant in North America. The current design flows to the plant are 82 MGD average, 110 MGD peak dry weather, and 240 MGD peak wet weather. The plant has 12 rectangular primary clarifiers (four new), each with a surface area of approximately 6,000 ft^2. Eight of the existing rectangular primary clarifiers, which were part of the original plant design, have a surface area of approximately 8,900 ft^2. Design peak hour SOR, with all eight tanks in service, is 1,550 gpd/ft^2.

A recent facility upgrade involved the addition of the four new chemically enhanced primary clarifiers with plates, a chemical feed system, a chemical diffuser, flash mixer, a flocculation stage, and low pressure air headers under the plates to assist in cleaning the plates when the unit is taken off line. The stainless steel lamella plates cover the entire surface area of the clarifiers. This approach was taken to consistently meet effluent quality standards and provide removal rates up to 90 percent TSS reduction prior to UV disinfection.

Wet weather operational strategy at Gold Bar will involve bypassing 160 MGD of screened raw sewage around the existing primary clarifiers and treating it in the new chemically enhanced portion.

For disinfection flows below 53 MGD will be treated in an expanded UV facility. Any flow in excess of this will be blended with the plant effluent and discharged at the existing outfall location. The construction of the expansion was completed in June 2009, but testing on actual wet weather events has not occurred. Operational history is not available for a review of actual removal rates.

The design criteria for the Gold Bar CEPT+plates are shown in **Table 7.2**.

Table 7.2 Design Data for the Gold Bar Enhanced Primary Treatment

Item	Value
Peak Wet Weather Flow, MGD	160
Clarifier Bays	16
Width, ft	14.5
Length, ft	90
Depth, ft	20
Plate Length, ft	6.3
Plate Angle, degrees	60
Plate Spacing, ft	0.3
SOR, gpd/ft^2	
Surface Area	6,600
Horizontal Projected Area	730

The SORs for the chemically enhanced portion of the Gold Bar facility are higher than what has been seen at existing facilities in the United States and approximately one-third of what was documented in the pilot facility operations.

7.3 Design Concerns for Plates

During the pilot study, failure of the CEPT+plates was typically associated with solids carry over. Carry over was believed to have been cause by one of the following:

- The high weir loading in the pilot may have contributed to short circuiting in the plates, which encourage carry over of solids
- Some solids that settled in the CEPT section were carried over to the CEPT+plates section when the sludge blanket was allowed to rise, which impacted settling from the plates.
- Some plates may have become loaded with TSS due to material sticking on the plate surface. Sticky particles increase the coefficient of friction of the plates adding turbulence and inhibiting performance if the plates are too close together.

In full-scale plants, plate spacing, depth, and angle are key design elements used to maximize solids removal and ensure a settling velocity of 0.2 to 0.4 feet per minute. Typical design considerations include the following:

- Plate spacing – Plates are typically stainless steel and the tighter the pack spacing, the more expensive the installation. The ultimate plate spacing will be a balance in cost of the plates, foot print and operations concerns on cleaning the plates after a run. At full-scale plants, plates are typically no closer than 4-inches apart.
- Plate depth – Plate depth takes away from storage in a full scale installation. As with plate spacing, the depth will be an economic and operations decision. The depth of plates is determined in part by the sludge management method and the required hydraulics of the unit.
- Plate angle – Most plates that are designed to self clean or discharge solids out the bottom are angled between 55 and 65 degrees off of horizontal. Flatter angles yield more horizontal projected area but can accumulate sludge. The extreme case for plates is a stacked clarifier where each plate section has its own sludge scraper (Deer Island, Boston, MA). In this configuration, the whole plate area is the horizontal projected area for solids to settle.

7.3.1 UV Disinfection

It should be noted that there is a great potential for scale buildup and ballast/lamp failure for a limited use facility. This is an operations and maintenance item that will need to be taken into account for any full scale design